TRANSACTIONS
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CHICAGO AND THE CONVENTION

CHICAGO, a city of tireless energy and formidable strength, an interesting, hospitable, alluring, extraordinary city—this is the city where the next convention and exposition of the American Society for Steel Treating will be held during the week of September 20, 1926.

But simply to say that Chicago is a great city does not do it justice. There are so many points of interest in Chicago that it is indeed difficult to know just what to describe owing to limited space.

The city is rich in its appeal to people of various tastes. Its diversified industries and business, its great shops, its splendid parks and boulevards, its excellent hotel facilities, its various recreational advantages afforded by the lake, its theaters, art museums, and libraries all contribute to the comfort and pleasure of its own people and the stranger who comes to it for the first time.

As one approaches the city, he beholds veritable mountains of buildings towering high one behind the other, not in broken lines like other cities, but en mass. Broad and massive, and for the most part rectangular in shape, they have the appearance of huge boxes with tier upon tier of windows. Constructed of steel, brick and mortar, they rise sublimely toward the sky—the mute yet expressive testimony of man's ingenuity and creative brain power. They house much of the business of the greatest nation on earth. To the visitor, the business section of Chicago is the feature with which he is first, if not most, impressed. It is metropolitan in the extreme. The absence of open squares and monuments and the almost uniform height and shape of the buildings gives a sense of compactness and similarity in all the street scenes in the central portion of the city.

The Chicago river and its two affluents divide the city into three sections. The north section is mainly a residence district

with warehouses and manufacturing plants down toward the river. The west side is given over largely to residences and also has great manufacturing areas, lumber yards and retail stores. The south side, while containing residence areas is to the west and extreme south devoted largely to manufacturing. The "Loop" or business center is at the north end of the south side. Here are immense wholesale and retail establishments, famous department stores, office buildings, large banks, theaters, hotels and public buildings. Here the elevated and surface cars bring and take the many thousands of human beings who are carrying on the enterprises which make this one of the greatest cities on the face of the earth. Over 150,000 vehicles and 20,000 elevated and surface cars pass through this "Loop" every 24 hours.

The city has been wisely planned with wide and long streets intersecting for the most part at right angles, which gives it a rectangular appearance as a whole.

The base lines for numbering streets running north and south and east and west are Madison and State streets respectively and by actual count this is the busiest corner in the world. Eight of the largest retail stores in the world are located on State street. Western avenue is the longest thoroughfare in the city, extending from its southern to its northern limits. La Salle street is the main street in the financial district. Michigan Boulevard extends along the lake front for a mile or more; a famous one-sided street where are located some of the best retail shops, hotels and office buildings.

The central manufacturing district is comprised of about 300 acres in the very heart of the city located in the vicinity of Thirty-fifth street and Morgan avenue. It is connected with every railroad that operates in and out of Chicago. Over 10,000 loaded freight cars are shipped by the industries annually. The "district," as it is called, is really a city unto itself with all the facilities for carrying on big business.

While Chicago has extensive residence districts, which are located for the most part away from the center one hears very little pertaining to them. Many of its citizens live in hotels and enormous apartment houses. In fact, the visitor is especially impressed with the size of everything in Chicago.

The business section of Chicago has always remained where it began. This is in contrast to other cities where the business

section is constantly shifting and following the population away from the original location.

Chicago's municipal progress is in a large measure due to the scientific and comprehensive plan for the future worked out and presented to the city by the Commercial Club in 1908. One of the chief aims of this plan is the opening up of parks and boulevards so that the citizens and visitors may have easy access to the pleasures and recreations of the lake. Its long and broad streets and boulevards relieve congestion and expedite travel. The lake contributes to the healthfulness of the climate and moderates extremes of

A View of Chicago in Its Earlier Days

temperature. Much attention has been given to hygienic and sanitary measures and for the disposal of its sewage. By means of the Drainage Canal the sewage of the city is carried away from the lake to be finally dispersed into the Gulf of Mexico by way of the Mississippi River. This has aided very materially in making Chicago a healthy place to live in. The Drainage Canal was put into service in 1900 after many years of engineering difficulties and at a cost of more than $80,000,000. It is designed to serve not only as a drainage canal but also as a ship canal for the navigation of large vessels. Through the medium of the Drainage Canal the current of the Chicago River was reversed and instead of flowing into Lake Michigan as it did naturally, it has been caused to flow in the opposite direction into the Mississippi river. By means

of this reversal of flow, the waters of Lake Michigan, Chicago's source of water supply, are not contaminated with wastage. This, no doubt, is one of the big factors contributing to Chicago's exceedingly low death rate. The Canal now has a fall of 40 feet in its length of 36 miles, and it is about 24 feet deep, 164 feet wide and approximately 4,000,000 gallons of fresh water from Lake Michigan flow through it every minute.

Markets are determined by the movement of population, industrial and agricultural growth, and are fixed by the inexorable laws of trade and commerce. People left the east which was rapidly becoming congested and travelled westward. Food and shelter are the prime requisites of immediate life. In the west they found rich agricultural fields where they raised grain and the prairies afforded abundant food for cattle. But these did not suffice. They needed the products manufactured in the east. Chicago being situated near both the center of area and the center of population became the distributing point of the country. To carry the grain and cattle to the east and the manufactured merchandise to the west, it was necessary to construct railroads. As the population, which is really the producer and consumer, increased, the demand for all things which make life comfortable increased. More and more rails were laid, iron and steel became a great necessity in supplying human needs. And so we see that Chicago made the railroads and not vice versa as many people suppose. Today, it is the foremost railroad terminal and it is said that some 1400 passenger trains arrive and depart daily carrying about 200,000 passengers.

Its water carrying trade is on a par with that of New York and Boston and exceeds that of any other port in America. Here may be seen great steel ships in all stages of construction from the laying of the keel to those majestically carrying products to distant ports.

It is said that the demand and use of iron and steel is the best measure of a nation's prosperity—so universal is its use. The rich iron ore deposits of Lake Superior which supply 4/5 of the iron consumed in the United States are close at hand and approximately 40,000 square miles of bituminous coal deposits lie just to the south of the city. Blast furnaces were constructed to make steel from which Bessemer steel rails were rolled. These were followed by the open-hearth which turned out better products. The car wheel industry located works near the smelters and as steel was demanded

The Tribune Tower

in great quantities, Chicago and its suburbs became great producers of that commodity. Their markets are just outside the door of the blast furnace.

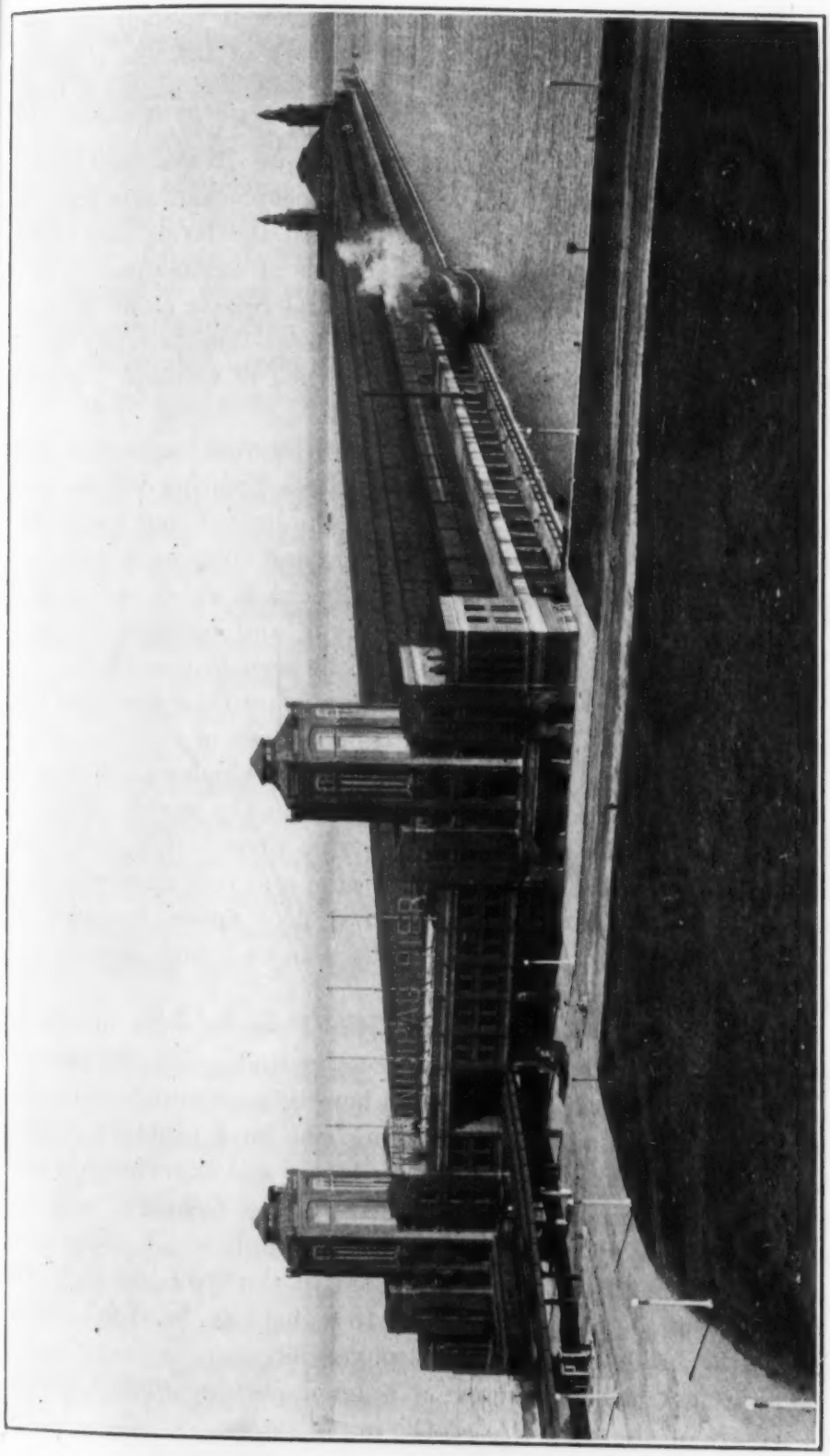
Chicago's whoelsale trade amounts to over $6,000,000,000 annually. It is the world's greatest livestock, grain and lumber market. In Chicago is located the principal meat packing center of the world. The Union Stockyards comprise 475 acres and afford accommodations for 500,000 cattle and horses. It disposes of $3,000,000 worth of living animals every day in the year and actual delivery of the property is made, which is not true of many other commodities bought and sold in Chicago. The scientific methods and mechanical appliances used in the various departments manufacturing the many by-products are of interest. The activities of the stockyards are a feature of enormous magnitude in the business life of the city.

Chicago is also the main lumber market in the United States and not only quantities but some 85 or more varieties of wood are obtainable. It is without a doubt one of the largest furniture markets in the world.

It is rather singular that while Illinois ranks third in the output of bituminous coal, and coke plays an important part in the manufacture of iron and steel, that much of the coke used is brought from the eastern states. The cement industry of Chicago has grown to great capacity and its product is shipped to all parts.

But if one would come to know the "spirit" of Chicago let him pay a morning visit to the Chicago Board of Trade at La Salle and West Jackson Boulevard. Here are focused the eyes of the world for this is the largest grain and provision market on earth. Traders are determined to buy low and sell high and so great is the din while the barter is on that speech is useless—a toss of the head, a turn of the hand, thumbs up or down all have a very definite meaning, and commodities are bought and sold with lightning rapidity. Here the bulls and the bears still contend for superiority.

One of the greatest assets for growth, development and progress of a community is its facilities for rapid transit and especially is this true of cities with vast populations. In Chicago, the "loop" which is about a mile long and half a mile wide with double tracks furnishes a turning point for all street cars, both surface and elevated. More than a dozen tunnels under the Chicago River facilitate transportation. Indeed, most of the merchan-



Municipal Pier—Where the Eighth Annual Exposition of the American Society for Steel Treating will be held September 20-24, 1926.

dise, coal, ashes and rubbish is hauled through tunnels 40 feet below the surface of the earth. This network of tunnels of about 60 miles is connected with many of the business houses. Here shipping from all points goes on 24 hours of the day.

Chicago has some 47 movable bridges and 76 stationary ones which also expedite the transportation of people and merchandise from one end of the city to the other. All the large mail order houses receive and dispose of vast quantities of commodities in this manner. They do a tremendous business and receive on an average of 275,000 letters every day. One of the most famous retail stores in the world, and perhaps the most renowned of Chicago, handles, at times, 35,000 telephone calls per day.

It is in this great city that the eighth annual convention and exposition of the American Society for Steel Treating will be held from September 20 to 24. This will be the largest and most complete exposition of equipment for working and treating metals ever held. Millions of dollars worth of equipment in great variety will be on exhibition. Automatic, electric, gas and oil-fired furnaces used in the heat treatment of steel will be seen in operation.

Seventy-five per cent more exhibition space than was used last year has been engaged and there will be 2 miles of exhibits of the very latest variety in this enormous exposition which will be located on Municipal Pier, one of the longest piers in the world. This, by the way, is one of the most interesting structures in Chicago. The pier is about 3000 feet long, 292 feet wide and cost approximately $4,000,000. Over 80,000 square feet of floor space, exclusive of aisles has been allotted to the three hundred and seventy-five exhibitors.

Every one who makes, sells, buys or works with metals or machinery will find interesting, instructive and profitable ideas at this convention and exposition. And here he may mingle with men of common purpose and understanding who have problems similar to his own and he may profit from the labors and experience of others and from what he sees and hears. The technical program scheduling papers by well-known men on subjects which are of vital interest and benefit to all men engaged in the steel industry will be presented at the technical sessions to be held at the Hotel Drake, which is the headquarters of the convention.

This is not merely a show; it is an important annual institution, a part of the very life of the organization.

It is not a question of whether you can afford to go. The truth is you cannot afford to stay away. Exhibitions of this kind not only awaken enthusiasm and creative imagination, two of the most valuable assets in industry, but they are the most forceful sales agencies in existence. Interest was so keen last year that 90 per cent of the exhibits were sold on the floor and many orders were taken for future delivery.

No matter where you live the road leads to Chicago, for Chicago is easily accessible from all parts of the world. You will find large and comfortable hotels at your service. If you have not already done so, may we suggest that you make your hotel reservation now.

PLANT INSPECTION

PLANT inspection for the National Steel and Machine Tool Exposition and Convention of the A. S. S. T. the week of September 20th, is under the direction of Theodore E. Barker, 12 North Campbell Ave., Accurate Steel Treating Co., Chicago, whose committee has made arrangements for scheduling plant inspection on Tuesday, Wednesday and Friday afternoons. Optional visits for these days have been provided. Considering the wide variety of manufacturing in Chicago there will, undoubtedly, be many members and guests who will desire to take these trips. Mr. Barker's committee has further provided for inspection of other plants than those included in the main group. These trips may be made upon application to the committee.

A complete list of the plant inspection trips will appear in the September issue of TRANSACTIONS.

S. A. E. PRODUCTION MEETING

THE Production Meeting of the S. A. E. is to be held in Chicago the same week as the Convention of the A. S. S. T. and National Steel and Machine Tool Exposition, the week of September 20th.

The tentative program calls for technical sessions on Tuesday, Wednesday and Thursday, September 21st, 22nd and 23rd.

Addresses by experts will cover the design, installation and application of conveyors. The papers on this topic will be enlivened by the showing of motion-picture films and other illustrative material that will bring the spirit of mass production into the meeting.

A real Production Meeting would be incomplete without a thorough consideration of the many angles of gear manufacture. From the selection of raw material and through the machining and heat-treating processes, the automotive gear will be conducted by engineers who know.

A paper on inspection along the line will open the Inspection Session. Following this, a symposium on interesting inspection devices will be held. A number of chief inspectors have already agreed to enter this symposium and will describe what might be termed "special gadgets" that have been found useful for inspection in their own plants but that are not known generally to other inspectors. Through the symposium a valuable interchange of information will be effected.

What Goes Wrong with Machine-Tools and Fitting the Tool to the Job will be the principal topics brought forth in the Machine-Tool Session.

The Sherman Hotel will be the headquarters for the S. A. E. and the technical sessions will be held in that hotel.

A. S. M. E.

THE Council of the A. S. M. E. has authorized the Society to participate in the A. S. S. T. Convention to be held in Chicago the week of September 20th. The participation of the A. S. M. E. will take the form of a day's sessions on machine shop practice to be contributed by the Machine Shop Practice Division of the A. S. M. E.

INCREASING INFLUENCE

THE rapid growth of the A. S. S. T. from a small beginning a few years ago to its present size of over 4,000 members, has been accomplished largely by the remarkable good will the association has developed among the industry it represents, as well as the whole-hearted co-operation that has been exercised by all of the members. This splendid spirit of co-operation, of belief in the organization and endeavor to spread its numerous benefits in the surrounding territory is ably exemplified by the activities of the Detroit chapter.

Located, as it is, on the site of remarkable activities in iron and steel, and surrounded by numerous smaller centers actively engaged in the production of articles requiring the service and aid of members of the organization, the Detroit chapter has for

the past four years been engaged in the policy of extension activities by means of which the Society is able to be of benefit to the greatest number.

Regular meetings have been held at Ann Arbor, at the University of Michigan, and matters have progressed at present to the extent where Professor Campbell is Chairman of the Ann Arbor Group, and arrangements will be made for the holding of regular meetings there at stated intervals, with the co-operation of the Detroit chapter.

For all effects and purposes a group of the A. S. S. T. actually exists at Ann Arbor, although it functions directly under the Detroit chapter, and not the National Society. This is the first instance in which a Group is operating under the direction of the chapter.

Further extension meetings are planned for Lansing and Flint during the coming winter. These are arranged through the active co-operation and support of the members residing in those localities. The spirit exemplified by Detroit is not unusual, but typical of the full measure of energy displayed by all chapters in the one endeavor to serve the interests of the industry within their field of influence. So, it can be readily recognized, that the remarkable growth of the A. S. S. T. is not so much unusual as it is the natural result of united effort.

ARMY ORDNANCE ASSOCIATION

THE Board of Directors of the A. S. S. T. has received a resolution adopted by the Board of Directors of the Army Ordnance Association in which it takes great pleasure in extending to the members of the A. S. S. T. a cordial invitation to attend the Eighth Annual Meeting of the Army Ordnance Association which will be held at Aberdeen Proving Ground, Maryland, October 8th, 1926.

The annual meetings of the Army Ordnance Association are devoted to demonstrations of the latest developments in all types of ordnance, and offer unusual opportunity to witness the present state of munitions preparedness in our country. This is a matter which will, no doubt, have great appeal to many members of the A. S. S. T. and it is hoped that a great many of them will avail themselves of this opportunity.

More complete details will be published later in TRANSACTIONS.

UNAUDITED PROFIT AND LOSS STATEMENT AMERICAN SOCIETY *for* STEEL TREATING

For the period from January 1 to June 30, 1926

INCOME			
Gross Dues			$27,097.18
Transactions Advertising		$18,781.29	
Transactions Sales		551.65	
Transactions Subscriptions		781.67	20,114.61
Reprints			256.55
Bindery Account			556.60
Book Account			1,257.14
Pencil Account			32.50
Pins and Buttons			22.00
Miscellaneous Receipts			167.22
Data Sheets		909.56	
Data Sheet Binders		641.00	1,550.56
Discounts Received		279.00	
Interest		451.22	
H. M. Howe Medal Fund Income		61.98	792.20
Sustaining Exhibit Membership			7,525.00
TOTAL INCOME				$59,370.96
EXPENSE			
Local Chapters			$13,781.89
Transactions			17,131.25
Reprints			334.39
Bindery Account			428.29
Book Account			859.17
Pencil Account			.45
Library			85.74
Data Sheets			2,382.33
Data Sheet Binders			578.80
Discounts Allowed			232.78
Bank Exchange			3.83
E. D. Campbell Memorial Lecture			322.45
General Expense			3,283.23
Secretary's Office			4,646.65
President's Office			1,529.47
Treasurer's Office			1,752.34
Director's Expenses			1,892.58
National Committees			2,335.04
Old Accounts Cancelled			115.00
TOTAL EXPENSE				$51,695.68
EXCESS INCOME OVER EXPENSE				7,675.28

BALANCE SHEET

As of June 30, 1926

ASSETS			
Commercial Account—Cleveland Trust Co.			$11,969.38
Savings Account—Cleveland Trust Co.		$ 5,302.08	
Equity Savings & Loan Co.		17,405.34	
Union Trust Co.		4,171.62	26,879.04
Accounts Receivable—Advertising		2,329.18	
Miscellaneous		2,186.24	
1925 Convention		48.00	4,563.42
Accrued Interest			305.81
Investments			63,235.00
Office Furniture and Fixtures			785.75
Inventory			2,452.65
1926 Convention Prepaid Expenses			9,511.96
1927 Convention Prepaid Expenses			344.35
TOTAL ASSETS				$120,047.36
LIABILITIES, RESERVES AND SURPLUS			
Accounts Payable			$ 1,503.93
1926 Convention Advance Receipts			24,501.00
Reserves for:			
Past Due and Doubtful Accounts		$ 890.25	
Dues Paid in Advance		10,000.00	
Permanent Convention Reserve		20,000.00	
H. M. Howe Medal Fund		5,000.00	35,890.25
Surplus—January 1, 1926		52,476.90	
Less—Increase to H. M. Howe Medal Fund		2,000.00	
		$50,476.90	
Plus—Excess Income for period from January 1 to June 30, 1926, per Profit and Loss Statement attached		7,675.28	
Present Surplus			$58,152.18
TOTAL LIABILITIES, RESERVES AND SURPLUS				$120,047.36

SOME FACTORS AFFECTING COERCIVE FORCE AND RESIDUAL INDUCTION OF SOME MAGNET STEELS

By J. R. Adams and F. E. Goeckler

Abstract

In this article the authors have considered the coercive force and residual induction of magnet steels as applicable to commercial problems.

The metallurgical factors that have the greatest influence on these values are: composition, melting, casting, rolling or forging, and heat treatment.

The authors have covered each of these factors and give a number of tables which show the effects of these factors upon the magnet steels which were investigated.

ADVANTAGE has been taken of the magnetic properties of steel for a great number of years in various ways, but the rapid electrical and mechanical development of the last three-quarters of a century has required that magnet steel give a better and better account of itself from year to year. This increase in performance has required a more critical survey of magnet steels for special purposes. The usual properties, such as tensile strength, elastic limit, etc., are of little avail in determining the suitability of a steel for magnetic use. A general knowledge of these properties for manufacturing purposes and for service conditions are, of course, essential, but the correlation between these properties and the results obtained on magnets in service are at present not well established. This compels us to examine magnet steel in an entirely different manner to determine its suitability for magnetic purposes.

It can be stated generally that the usual tests made to select steels only approach the conditions imposed by actual service. The same statement applies to an even more marked degree in magnetic testing of straight bars. It is true that we can determine the absolute values of coercive force, maximum induction, residual induction, etc., on simple test specimens. That these will

A paper presented before the Cleveland Convention of the Society, September, 1925. Of the authors, J. R. Adams is superintendent of the research department, and F. E. Goeckler is assistant superintendent of the heat treating department, Midvale Co., Nicetown, Philadelphia.

foretell the behavior of the steel in service when in the more complicated shape of an actual magnet cannot be claimed, but in striving for high magnetic values so determined, a step in the right direction is at least being taken. This situation arises from three reasons:

1. No perfectly satisfactory theory of magnetism has been advanced.[1]

2. So little knowledge exists respecting complicated magnetic circuits.

3. No correlation exists between the absolute values determined on straight bars, and the empirical tests on which the manufacturers of magnets usually rely.

The instruments most commonly used, such as the Burrows, Fahy and Koepsel permeameters, etc., all require straight bars to determine the magnetic properties of the steel being tested. On the other hand, commercial permanent magnets are made in a multiplicity of shapes and sizes, few being straight bars. These vary from the heart-shaped magnet of the watt-hour meter to the straight short magnet of a motorboat igniter, varying in weight from a few ounces to several pounds. Lack of knowledge respecting magnetic circuits makes it impossible to foretell the effect these shapes will have on the performance of the steel in the form of magnets. Consequently, each manufacturer of magnets develops his own series of tests by which to determine the suitability of the magnet steel for his particular purpose. It only rarely happens that these empirical values can be interpreted in terms of absolute magnetic values as determined on the straight bar permeameters, and, since these empirical tests take forms as various as the shapes of the magnets, the testing of magnets becomes an art suiting the convenience of the manufacturer and his interpretation of what constitutes a good magnet.

Due to the multiplicity of these tests it is impractical for the manufacturer of magnet steel to apply them. They would require the actual manufacture of magnets in most cases and more instruments than any one laboratory would be justified in carrying. This situation has compelled the manufacturer of magnet steels to rely almost entirely on the absolute magnetic values as determined by the straight bar testing instruments for guidance in the development of permanent magnet steels and the

[1]McKeehan, *Journal*, Franklin Institute, Vol. 197, May and June, 1924.

effect of metallurgical factors on these absolute values. In all of the following the values given were obtained from straight bars tested on the Burrows' permeameter under a magnetizing force of 300 C. G. S. units, except where otherwise noted. The bars were 1 x ¼ inches in cross-section and 10 inches long in all cases. The specimens investigated by the authors represent production heats in many cases, but, in others, the bars were rolled from 3-inch experimental ingots made especially for the purpose. These investigations were carried out to obtain data applicable to particular commercial problems under consideration at the time, consequently, no comprehensive research plan has been followed. The magnetic values usually considered are residual induction, coercive force, the general shape of the hysteresis curve and mathematical combinations of these values. In this paper we have considered the coercive force and residual induction only.

The metallurgical factors that have the greatest influence on these values are composition, melting, casting, rolling or forging, and heat treatment.

Composition

A—Plain Carbon Magnet Steels

The first steels used for permanent magnets were plain carbon steels. It was early recognized that the amount of carbon present was an important factor, in that it increased the coercive force, but, at the same time, decreased the residual induction.[2, 3] Curve 1[4] presents graphically the increase in coercive force with the increase in carbon content, and indicates that above approximately 1.00 per cent carbon the benefits derived from further addition of carbon with respect to increasing the coercive force are of little value, when the magnets are quenched from 1472 degrees Fahr. If, however, the quenching temperature is raised the coercive force continues to rise[2] with an increasing carbon content, but at a slower rate than observed below 1.00 per cent carbon. It is impractical, however, to quench magnets from a temperature as high as that necessary to take advantage of the

[2]Gumlick, *Transactions*, Faraday Society, Vol. VIII, 1912, page 98.

[3]Dowdell, TRANSACTIONS of A. S. S. T., Vol. V, page 64.

[4]Burrows, Scientific Papers, Bureau of Standards, No. 272.

rise in coercive force produced by the higher carbon content, so that few magnets are made from steel containing more than 1.00 per cent of carbon.

The decrease in residual induction over that in pure iron brought about by the increase in carbon content up to approximately 1.00 per cent has to be accepted in order to obtain the property of permanence in the magnet. Carbon magnet steels are not widely used and only where service conditions are not severe. They are apt to give non-uniform results, especially in large sections.

Table I

Effect of Carbon on Tungsten-Chromium

Tungsten 6.00 Per Cent: Chromium 0.75 Per Cent

Steel	C	W	Cr	Normalized Degrees Fahr.	Quenched in light oil from Degrees Fahr.	B_r	H_c
A	1.46	5.79	0.76	1508	1490	7690	51.8
B	1.32	5.87	0.77	1508	1490	7980	78.3
C	1.19	5.85	0.73	1508	1490	7170	77.9
D	1.07	5.74	0.75	1508	1490	8250	77.9
E	0.93	6.01	0.77	1508	1490	9110	74.3
F	0.85	6.01	0.75	1544	1490	9140	75.4
G	0.75	6.05	0.76	1562	1526	9000	79.9
P	0.60	5.91	0.81	1616	1562	11150	76.0
H	0.51	6.04	0.74	1616	1598	11190	70.1
I	0.43	6.01	0.75	1688	1598	8760	57.4
K	0.30	6.10	0.76	1688	1670	8820	46.1
L	0.21	6.08	0.74	1706	1670	8620	46.1
M	0.11	5.38	0.73	1742	1724	8720	30.2

Values from Parkin—Iron and Steel Institute, Carnegie Scholarship Memoirs—Vol XIII, 1924.

B—Tungsten Magnet Steels

These were among the first alloy magnet steels to be developed and exploited. As this is a binary steel the relation between the various constituents becomes quite complex. The addition of tungsten to plain carbon magnet steel raises the coercive force, and, at the same time, maintains the residual induction at a high value, but the optimum percentage of carbon is not generally considered to be 1.00 per cent but in the neighborhood of 0.60 per cent.

Table I shows[5] the effect of carbon on 6.00 per cent tungsten steel containing 0.75 per cent chromium, from which it is seen that 0.60 per cent carbon gives the highest desirable combination

[5]Values from Parkin, Iron and Steel Institute, *Carnegie Scholarship Memoirs*, Vol. XIII, 1924.

of residual induction and coercive force. Table II confirms this, since there is no gain in magnetic properties in raising the carbon from 0.71 to 1.00 per cent. In Table II the lower coercive forces and residual inductions than those obtained by Parkin are due to the lower tungsten, absence of chromium and the fact that the

Table II

Effect of Carbon Between 0.70 Per Cent and 1.00 Per Cent on Tungsten Magnet Steel

Bars drawn at 1375 degrees Fahr. for 5 hours cooled slowly.

			Quenched from 1600° F-water		Quenched from 1600° F-oil	
Heat	C	W	B_r	H_c	B_r	H_c
MKD-654	0.71	5.45	10275	58.0	9250	64.5
MLE-98	0.78	5.00	9900	59.0	9150	61.0
MLE-58-x	0.84	5.00	9600	57.5	9100	62.0
MNE-112	1.00	5.70	8500	67.5	7200	71.5

Table III

Effect of Chromium on 0.98 to 1.13 Per Cent Carbon Steel

Bars drawn at 1100 degrees Fahr. for ½ hour and cooled slowly before hardening.

			Hardened from 1500° F-oil		Hardened from 1500° F-water		Hardened 1580° F-oil		Hardened 1580° F-water	
Heat	C	Cr	B_r	H_c	B_r	H_c	B_r	H_c	B_r	H_c
4-8587	1.13	0.70	10425	30.25	9450	63.50	7200	62.00	8350	63.50
MKD-57	1.02	1.33	8825	60.35	9725	62.50	8000	69.00	All bars cracked	
MKD-830	1.00	1.75	9200	63.00	9875	58.00	8550	67.00	8730	61.50
MLE-49	1.02	2.25	9500	64.00	10300	56.25	8950	66.75	All bars cracked	
MLE-48	1.00	3.15	10150	63.75	10575	56.25	9230	68.10	All bars cracked	
MLD-301	1.02	4.08	9900	65.00	10200	58.25	9400	70.00	All bars cracked	
MLE-57	0.98	6.07	....	....	10150	56.00-1	9600	72.00-2	All bars cracked	
MLE-28	1.04	8.93	....	....	9300	59.50-3	9400	73.5-4	All bars cracked	

1—Quenched from 1525 degrees Fahr. water.
2—Quenched from 1625 degrees Fahr. oil.
3—Quenched from 1550 degrees Fahr. water.
4—Quenched from 1650 degrees Fahr. oil.

steels were drawn at 1375 degrees Fahr. for 5 hours. Percentages of tungsten as low as 5.00 give good magnetic properties, but 3.00 per cent tungsten is too low to give the best results, as indicated by two steels containing 2.84 per cent and 2.93 per cent tungsten, which gave residual inductions of 6500 and 7150, and coercive forces of 56.0 and 56.5, respectively.

C—Chromium Magnet Steels

The recent commercial trend in permanent magnets has been toward the chromium steels. They originally started with comparatively low percentages of chromium, but at the present time there is a strong tendency towards higher chromium, using up

Table IV
Effect of Carbon on Low Chromium Steel
Bars drawn at 1100 degrees Fahr. for ½ hour and cooled slowly before quenching from 1580 degrees Fahr. in oil.

Heat	C	Cr	B_r	H_c
MKS-221	0.40	0.84	10000	39.00
A-3073	0.61	0.86	9950	43.75
9-5988	1.08	0.77	7200	65.50
4-8587	1.13	0.70	7200	62.00
A-3334	1.35	0.69	7250	55.00

Table V
Effect of Carbon on Some 2.50 Per Cent Chromium Steels
Bars drawn at 1100 degrees Fahr. for ½ hour and cooled slowly before hardening.

			Quenched from 1500°F-oil		Quenched from 1500°F-water		Quenched from 1580°F-oil	
Heat	C	Cr	B_r	H_c	B_r	H_c	B_r	H_c
MKD-695	0.83	2.44	10250	60.00	11150	53.70	9200	60.00
MKD-872	0.91	2.18	9850	63.00	10625	55.00	8600	63.00
MLE-49	1.02	2.25	9500	64.00	10300	56.00	8900	66.70
138-2	2.37	2.49	5650	62.00	6800	68.00	5250	66.00

Table VI
Effect of Carbon on 3.00 Per Cent Chromium Steels
Bars drawn at 1100 degrees Fahr. for ½ hour and cooled slowly before hardening.

			Quenched from 1500°F-oil		Quenched from 1500°F-water		Quenched from 1580°F-oil	
Heat	C	Cr	B_r	H_c	B_r	H_c	B_r	H_c
MLE-55	0.65	3.18	10250	56.5	10700	48.5	10000	58.5
MLE-30	0.83	3.05	10400	60.0	11000	53.0	9600	62.0
2-1922	0.90	3.04	10200	63.0	10800	56.0	9200	65.5
MLE-48	1.00	3.15	10100	64.0	10550	56.0	9300	68.0
MLE-49	1.11	2.99	9450	66.5	10400	60.0	9000	70.5
MLE-129	1.24	3.05	8650	65.5	9750	61.0	8150	71.5
MNE-48	1.32	3.12	8750	66.0	9450	58.0	8300	71.0

to as high as 6.00 per cent. So far the results obtained indicate that the increase in magnetic values obtained from greater percentages of chromium than 4.00 per cent are not commensurate with the increased cost. Table III shows the effect of chromium on 1.00 per cent carbon steel, wherein the residual induction is raised continuously as the chromium is increased to about 3.00 to 4.00 per cent. The highest combination, however, of residual

induction and coercive force seems to lie in the neighborhood of 4.00 per cent chromium. The influence of carbon on some chromium steels is shown by Tables IV, V and VI, which indicate that the best carbon percentage is slightly above 1.00 per cent. Greater percentages than these only increase manufacturing difficulties and hazards and are of doubtful value with respect to magnetic properties. Table IV shows the marked effect on the coercive force of varying the carbon content of low chromium steels from 0.40 to 1.08 per cent, and the decrease in these values above that percentage of carbon. Table V shows the effect of carbon on the coercive force of 2.50 per cent chromium steels and the increase of residual induction, due to the increase of chromium, is observed by comparing the values of Table IV with those given in Table V. Raising the carbon to 2.37 per cent decreased the residual induction to a marked extent, probably due to this high percentage of carbon reducing the available magnetic volume.[6] This is confirmed by the values obtained on 1.24 and 1.32 per cent carbon, 3.00 per cent chromium steels, shown in Table VI. The properties of a series of 6.00 per cent chromium magnet steels are given in Table VII. They are not high enough, however, to justify their selection over the 4.00 per cent chromium steels, as far as coercive force and residual induction are concerned. These properties are in agreement with those found by Gumlick.[7]

The addition of 0.34 per cent tungsten to 4.00 per cent chromium and 1.00 per cent carbon steel has no marked effect, but on adding 0.24 per cent vanadium to 4.00 per cent chromium and 1.00 per cent carbon steel it was found necessary to raise the hardening temperature over that ordinarily used in order to obtain the full values of the 4.00 per cent chromium steel; but no treatment of the steel containing vanadium caused any increase in coercive force or residual induction over that obtained from 4.00 per cent chromium and 1.00 per cent carbon steel. The chromium steels have the marked advantage over the tungsten steels in that they give their best values with an oil quench, while the tungsten steels are water-quenching steels.

D—Chromium-Cobalt Magnet Steels

Table VIII shows the properties of the addition of cobalt from 1.25 to 5.20 per cent to 2.50 per cent chromium steels. The co-

[6] Mars, *Stahl und Eisen*, Oct. 27-Nov. 10, 1909.

[7] *Stahl und Eisen*, Jan. 12, 1922, p. 42.

Table VII

Series of 6.00 Per Cent Chromium Magnet Steels

Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly, and quenched as shown.

		1545° F-oil		1600° F-oil	
C	Cr	B_r	H_c	B_r	H_c
0.85	6.00	9900	65.0	9400	71.5
0.97	6.02	9900	64.0	9300	72.0
1.05	6.09	9950	63.0	9300	75.0
1.16	6.20	9500	66.0	9100	75.0

Table VIII

Effect of Cobalt on 2½ Per Cent Chromium Magnet Steel

(All bars drawn at 1100 degrees Fahr. for 1 hour, cooled slowly).

No.	C	Cr	Co	Quenched in oil° F.	B_r	H_c	Quenched in water° F.	B_r	H_c
MLE-31-1	0.86	2.60	1.25	1500	10,260	59.5	1500	10,630	53.8
MLE-31-2	0.86	2.60	1.25	1525	10,270	59.5	1520	10,510	54.0
MLE-31-3	0.86	2.60	1.25	1575	8,960	60.0	1575	10,370	58.8
MLE-31-4	0.86	2.60	1.25	1575	8,950	61.0	1590	10,080	58.2
MLE-31-5	0.86	2.60	1.25	1650	8,360	59.0	1650	9,520	56.0
MLE-31-6	0.86	2.60	1.25	1640	8,625	59.3	1640	9,360	55.8
MLE-32-1	0.80	2.67	2.27	1525	10,440	61.5	1525	10,880	54.1
MLE-32-2	0.80	2.67	2.27	1540	10,400	59.5	1540	10,800	53.2
MLE-32-3	0.80	2.67	2.27	1600	9,950	60.2	1600	10,350	56.2
MLE-32-4	0.80	2.67	2.27	1600	9,820	60.0	1610	10,470	57.0
MLE-32-5	0.80	2.67	2.27	1650	9,290	56.4	1650	9,930	54.2
MLE-32-6	0.80	2.67	2.27	1650	9,100	58.2	1650	9,740	56.2
MLE-33-1	0.88	2.06	3.30	1550	8,240	75.1	1550	10,100	68.2
MLE-33-2	0.88	2.06	3.30	1550	8,330	75.6	1550	10,120	68.2
MLE-33-3	0.88	2.06	3.30	1625	8,370	74.2	1625	9,540	76.5
MLE-33-4	0.88	2.06	3.30	1625	8,390	75.0	1625	9,340	74.5
MLE-33-5	0.88	2.06	3.30	1675	8,970	75.8	1675	8,400	74.5
MLE-33-6	0.88	2.06	3.30	1675	8,300	75.2	1675	8,580	75.5
MLE-61-1	0.82	2.59	5.20	1550	9,490	67.0	1550	10,480	64.0
MLE-61-2	0.82	2.59	5.20	1550	9,540	67.0	1550	10,570	65.2
MLE-61-3	0.82	2.59	5.20	1625	9,680	69.8	1625	9,460	68.8
MLE-61-4	0.82	2.59	5.20	1625	9,590	67.8	1625	9,780	68.9
MLE-61-5	0.82	2.59	5.20	1675	8,690	64.2	1675	8,940	63.5
MLE-61-6	0.82	2.59	5.20	1675	9,050	65.2	1675	8,590	63.0

ercive forces and residual inductions have been raised considerably over those obtained by 0.83 per cent carbon 2.44 per cent chromium steel shown in Table V. The properties, however, are not raised sufficiently over those obtained from 4.00 per cent chromium and 1.00 per cent carbon steel to offset the increased cost due to the addition of cobalt. Combinations of chromium-

cobalt-tungsten and manganese give exceedingly high coercive forces coupled with good residual inductions—a notable example is the K. S. Magnet Steel developed by Honda and Saito,[8] which gives values greater than a B_r of 8900 and H_c of 215.0.[9] These high alloy steels, however, are exceedingly hard to work, and in addition their value in the form of permanent magnets is still indeterminate.[10]

Melting, Casting, Rolling or Forging

The methods of melting, casting, rolling or forging have a great influence on the quality of magnet steel produced. The factors that enter into the melting of high grade alloy steels all apply here and are so well known that we do not need to discuss them. The type and design of ingot molds are governed by two factors: First, the type of equipment available to reduce the steel from ingot form, and second, the design should be such as to prevent excessively large crystallization and keep the pro-eutectoid carbide envelopes as thin as possible. This is important in the case of magnet steel, since, as will be brought out later, it is detrimental to apply heat treatments after forging or rolling to correct any influence which the initial crystallization of the steel may have on the final structure. From this it follows that it is desirable to cast magnet steel in as small ingots as practicable, thus insuring maximum uniformity of carbide distribution, a factor of extreme importance in permanent magnet steel. If the above precautions are followed, little difference has been found with respect to reduction in area, in sizes varying from $\frac{3}{4}$ x $1\frac{3}{4}$ inches to $2\frac{1}{8}$ x $\frac{3}{32}$ inches. When ingots are rolled to rough bar form and chipped, better magnetic qualities are generally obtained on the finished product if the rough bar has not been annealed for chipping. Finishing temperatures apparently have some influence on the final magnetic properties obtained from chromium magnet steel, but they apparently have no effect on tungsten magnet steel. Table IX shows the effect of various finishing temperatures in rolling on 1.00 per cent carbon and 1.75 per cent chromium and 1.00 per cent carbon and 4.00 per cent chromium magnet steels. When it is necessary to furnish the steel soft enough for cold shearing it is better, whenever possible, to cool at a controlled rate directly

[8] Honda and Saito, Phys. Math. Soc. of Japan, 3rd Series, Vol. II, No. 3.

[9] Sanford and Cheney, Sci. Papers, Bureau of Standards, No. 384.

[10] Dowdell, Transactions, A. S. S. T., Jan., 1924, Vol. 5, p. 27.

Table IX

Effect of Finish Rolling Temperatures on Chromium Magnet Steels

Carbon 1.00 Per Cent; Chromium 1.75 Per Cent

Bars drawn at 1100 degrees Fahr., cooled slowly. Quenched from 1580 degrees Fahr. in oil.

Temperature at start of rolling Degrees Fahr.	Temperature at finish rolling Degrees Fahr.	B_r	H_c
2200	1449	7850	64.0
2264	1485	8000	63.75
2264	1555	8100	63.30
2264	1695	7900	63.30
2264	1850	7700	66.00
Carbon 1.00 per cent; Chromium 4.00 per cent			
2250	1500	9250	66.50
2250	1600	9500	67.0
2250	1700	9300	67.5
2250	1800	8600	69.0

Table X

Heating Chromium Magnet Steel to Various Temperatures for Various Times

Carbon 1.03 Per Cent; Chromium 4.07 Per Cent

All bars quenched from 1580 degrees Fahr. in oil.

Temperature Degrees Fahr.	Time in hours Cooled slowly	B_r	H_c
As rolled		9100	72.00
1100	1	9200	71.00
	3	9500	70.00
	5	9500	69.00
	12	9600	68.50
	24	9900	68.25
	36	9850	67.00
1200	1	9700	69.00
	3	9700	66.50
	5	9800	66.00
	12	9900	62.75
	24	9800	62.00
	36	10000	59.50
1300	1	9925	65.00
	3	10150	61.50
	5	9900	61.25
	12	10000	57.00
	24	10000	55.00
	36	10200	54.00
1400	1	10200	57.00
	3	10100	55.00
	5	10100	52.00
	12	9700	51.50
	24	9800	49.50
	42	9400	48.00

from the rolls to obtain the desired softness, rather than to give a subsequent anneal or draw.

Heating of the steel for forging or rolling should be done as rapidly as possible, without doing it injury, both from the standpoint of decarburization and the prevention of excessive heating.

The effect of carbon on the coercive force has been shown in Tables IV, V, VI, and Fig. 1, so that one is not surprised to find the excessive decarburization from poor practice in manufacturing operations causes a marked deterioration in magnets made from such steel. Actual experience has led us to guard against this

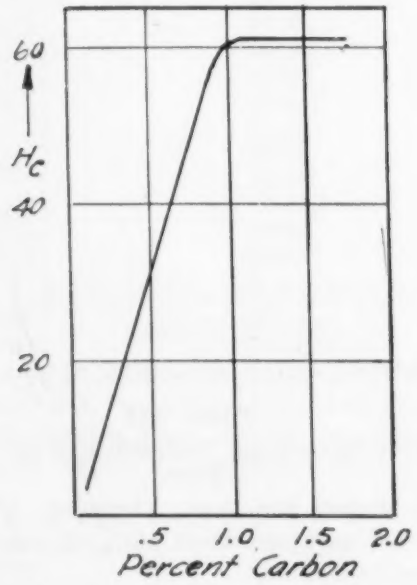


Fig. 1—Effect of Carbon on the Coercive Force.

most carefully. It is probable the lower coercive force of the decarburized surface allows the magnetic properties to deteriorate more rapidly in the surface areas than in the interior of the steel. This is indicated by testing with flux meter magnets made from decarburized steel and non-decarburized steel immediately after magnetization, when only a small difference is observed, but on allowing the magnets to stand for some time and remeasuring, it is found that the decarburized magnets have deteriorated in magnetic qualities much more than the non-decarburized ones. As most magnet steel is used with the rolled or forged surface intact the prevention of decarburization becomes an important factor in the production of high quality magnet steels.

Table XI

Heating Tungsten Magnet Steel to Various Temperatures for Various Times

Carbon 0.72 Per Cent; Tungsten 5.55 Per Cent

All bars quenched from 1600 degrees Fahr. in water.

Temperature Degrees Fahr.	Time in hours Cooled slowly	B_r	H_c
As rolled		10200	68.00
1200	1	10275	67.50
	3	10250	66.00
	5	10100	65.00
	12	10225	63.50
	24	10175	63.00
	36	10250	63.00
1300	1	10200	64.50
	3	10150	62.50
	5	10225	62.00
	12	10300	61.50
	24	10225	62.00
	36	10150	58.50
1400	1	10200	62.00
	3	10200	61.00
	5	10150	59.50
	12	10250	58.00
	24	10200	58.00
	36	10400	48.50

Table XII

Effect of Holding at Quenching Temperatures for Various Lengths of Time

Carbon 0.98 Per Cent; Chromium 1.75 Per Cent

(All bars quenched from 1580 degrees Fahr. in oil).

Time in minutes held at Quenching temperature	B_r	H_c
0	8750	65.0
5	8400	64.0
15	7900	62.0
30	7800	60.5
60	7600	59.5
120	7300	56.0

Heat Treatment

In reviewing the literature of magnet steel one is impressed by the slight attention paid to the history of the steels being investigated. There are some notable exceptions to this, of course, such as Parkin,[11] but, in general, this point has not been stressed to the extent its importance deserves. Many investigators have concerned themselves with composition only, neglecting all heat treatment

[11] *Carnegie Scholarship Memoirs*, Iron and Steel Institute, Vol. XIII, 1924.

preceding final hardening. From the fact that a variation of from 46.0 to 70.0 in coercive force can be obtained from the same composition with the same final hardening procedure by varying the previous heat treatment, it can be readily appreciated that

Table XIII

Effect of Air Quenching Before Hardening

Carbon 1.00 Per Cent; Chromium 1.78 Per Cent

Bars drawn at 1100 degree Fahr., for ½ hour, cooled slowly. Heated and air quenched, as given below, and quenched from 1580 degrees Fahr. in oil.

Air quenched from Degrees Fahr. for 5 minutes	B_r	H_c
As rolled	8400	69.0
1100	8400	68.5
1200	8925	68.0
1300	8750	66.5
1400	8400	65.5
1500	9125	64.5
1600	8850	64.0
1700	8900	68.5
1800	8500	68.0
1900	8600	69.0
2000	8100	68.0

Table XIV

Effect of Air Quenching Before Hardening

Carbon 0.83 Per Cent; Chromium 2.44 Per Cent

Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and air quenched, as given below, and quenched from 1580 degrees Fahr. in oil.

Air quenched from Degrees Fahr. for 5 minutes	B_r	H_c
1100	9200	61.0
1200	9200	61.0
1300	8800	61.0
1400	9000	58.0
1500	10000	58.0
1600	9800	57.5
1700	9500	58.0
1800	9300	58.0
1900	9200	59.5
2100	9000	59.0

heat treatment is as important as composition. Several of the factors previously discussed are practically heat treatment factors, but factors that can only be controlled during the melting, casting, rolling or forging, and, due to the complicated nature of the reactions which bring about the changes in magnetic properties, they cannot be corrected later.

The fact that in annealing billets, prolonged heating and slow cooling in manufacturing operations are all detrimental to the final magnetic qualities of the steel may be partially explained by dissociation of some of the compounds in the steel and the coalescing of some of the constituents. It is difficult actually to demonstrate this experimentally, due to lack of absolute control of the above mentioned operations, where one factor may be deliberately changed, while some other factor may have changed inadvertently during the experiment, but average results obtained over long periods of production demonstrate the above to be correct. Reasoning by analogy from results obtained on the annealing of finished magnet steel leads to the same conclusions. The results of heating chromium and tungsten magnet steel to various temperatures are indicated by Tables X and XI.

Tables X and XI show clearly the drop in coercive force caused by heating and the influence of time. These temperatures are all within the spheroidizing range and the higher temperatures, at which spheroidization occurs more rapidly and to a greater extent, cause a greater and more rapid drop in coercive force. Murakami[12] and others state that chromium forms various carbides that do not dissociate below the critical temperatures. If this is so, then the above results can only be attributed to the coalescing of the carbides which do not again become so intimately dispersed on subsequent quenching. It may be supposed that this could be overcome by holding at the final quenching temperature for longer periods, but this is not the case, as shown by Table XII, and when the statement of the above mentioned investigators to the effect that the chromium carbides dissociate when heated above the critical temperatures is considered, the results become more explainable. Their statement that chromium carbides dissociate into other carbides and free chromium accounts for the lowering of the residual induction, the free chromium forming a solid solution in the ferrite, thereby lowering the permeability and, consequently, the residual induction. The exact composition of the various chromium carbides have not been positively determined, nor have the extent and character of the reactions for various temperatures and compositions been established; but it is fairly well known that several exist, and it seems reasonable to believe that each one will have a different effect on the magnetic properties of

[12]Murakami, Science Report, Tohoku Imperial University, Vol. VII, No. 3.

Table XV

Effect of Air Quenching Before Hardening

Carbon 1.00 Per Cent; Chromium 4.00 Per Cent

Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and air quenched, as given below, and quenched from 1580 degrees Fahr. in oil.

Air quenched from Degrees Fahr. for 5 minutes	B_r	H_c
As rolled	9200	72.0
1100	9000	71.0
1200	9100	70.0
1300	9200	68.5
1400	9500	63.0
1500	9400	65.0
1600	9250	65.0
1700	9250	65.5
1800	9200	68.5
1900	7900	69.5

Table XVI

Effect of Air Quenching Before Hardening

Carbon 0.72 Per Cent; Tungsten 5.45 Per Cent

Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and air quenched, as given below, and quenched from 1600 degrees Fahr. in water.

Air quenched from Degrees Fahr. for 5 minutes	B_r	H_c
1200	10,300	65.0
1300	10,200	64.0
1400	10,000	64.0
1500	10,000	63.0
1600	9,950	62.5
1700	9,950	63.5
1800	10,000	62.5
1900	9,950	62.25

Table XVII

Effect of Slow Cooling Before Hardening

Carbon 1.00 Per Cent; Chromium 1.78 Per Cent

Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and cooled slowly, as given below, and quenched from 1580 degrees Fahr. in oil.

Cooled slowly from Degrees Fahr. for ½ hour	B_r	H_c
As rolled	8400	69.0
1100	8500	67.5
1200	8600	67.0
1300	8800	63.4
1400	9300	58.0
1500	9200	55.0
1600	8600	55.0
1675	8700	56.0
1800	8200	59.0

the steel, so that the formation of a new carbide or carbides affect the coercive force, since it is fairly well established that carbides are responsible for the property of coercivity in the steel. The figures given in Table XII indicate, as well, the loss in coercive force as the steel is held for an increasing length of time at the quenching temperature, which in some measure also confirms the theory of the change of the nature of the carbides when they are held above the critical temperature.

The above statement respecting the decrease in coercive force due to the agglomeration of the carbides is strikingly borne out by Tables XIII and XIV, which show the effect of heating the steel to various temperatures and air cooling before hardening. The minimum values all fall at 1600 degrees Fahr. Honda[13] states that for high carbon steel there is a spheroidization zone extending about 100 degrees Cent. above the critical temperature in which the excess carbides spheroidize, and that above this point total solution occurs. This seems applicable here since there is a rise in coercive force after 1600 degrees Fahr. is passed if the steel is heated rapidly, cooled quickly and not held so long that dissociation of the carbides is allowed to proceed to any extent. That this dissociation does occur is indicated by the fact that even when care was taken not to hold too long in the solution range, only in a few instances does the coercive force reach values as high as those obtained without preheating.

If the steel is heated to various temperatures, cooled slowly and then hardened, the minimum coercive force again occurs at about 1600 degrees Fahr., but above this temperature the values do not approach the "as rolled" values as do those obtained from bars air cooled from the same temperature. This would be expected, since the excess carbides that have been dissolved above this temperature are reprecipitated during the slow cooling. Cooling slowly from temperatures above the critical allows the dissociated carbides partly to recombine.[14] Tables XVII, XVIII, and XIX show the results obtained from bars so run.

The reaction that occurs in the tungsten steel is not so clear. The indications are that the effects noticed are only due to agglomeration of the carbides without dissociation of the constituent, but the sudden drop in coercive force noticeable on heating to

[13]Honda, Iron and Steel Institute, Vol. 102, 1920, No. 11, p. 261.

[14]Murakami, Science Reports of Tohoku Imperial University, Vol. VII, No. 3.

1800 degrees Fahr. for one hour and cooling slowly in Table XIX indicates that some further change takes place somewhere above 1700 degrees Fahr. This requires further investigation.

In addition, the effect of holding tungsten steel for various lengths of time at the quenching temperature does not affect the magnetic values to nearly the extent it does chromium steels.

The above factors discussed all have to be considered in the production of commercial magnets. Magnet manufacturers re-

Table XVIII
Effect of Slow Cooling Before Hardening
Carbon 1.00 Per Cent; Chromium 4.00 Per Cent
Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and cooled slowly, as given below, and quenched from 1580 degrees Fahr.

Cooled slowly from Degrees Fahr. for ½ hour	B_r	H_c
As rolled	9200	72.0
1100	9200	70.0
1200	9300	69.0
1300	9500	66.0
1400	9750	57.0
1500	9750	57.0
1600	9750	57.0
1700	9700	57.0
1800	9600	58.0

Table XIX
Effect of Slow Cooling Before Hardening
Carbon 0.72 Per Cent; Tungsten 5.45 Per Cent
Bars drawn at 1100 degrees Fahr., for ½ hour, cooled slowly. Heated and cooled slowly, as given below, and quenched from 1600 degrees Fahr. in water.

Cooled slowly from Degrees Fahr. for 1 hour	B_r	H_c
1100	10,200	69.3
1200	10,250	67.5
1300	10,200	64.5
1400	10,200	62.0
1500	10,100	60.0
1600	10,000	61.0
1700	10,000	58.0
1800	10,100	53.0

quiring soft material for cold stamping cannot expect to obtain the maximum magnetic values from the annealed material. Operations involving the heating of the steel for other than quenching, such as forging, bending, etc., all decrease the magnetic values, and if they are not carried out with due regard to avoid temperatures, periods of holding, etc., that are injurious, the decrease in magnetic values is likely to be considerable. However, if the

conditions are judiciously chosen and care taken to see that they are adhered to, the loss in magnetic values from such operations is not serious.

When softening for machining after forging, bending, etc., is required, loss in magnetic values must be expected. Whenever it is possible to avoid the softening of magnet steel for whatever purpose after its initial rolling or forging, it should be done. In the hardening operation a procedure should be adopted that will permit of the holding of the magnets at the quenching temperature the least time possible to obtain the maximum magnetic values.

Conclusion

To sum up, it must be borne in mind in treating and quenching magnet steel that there are apparently two factors that oppose each other, the obtaining of the maximum amount of carbides in solution, the best conditions for which are the best conditions for the detrimental dissociation of the carbides, so the conditions that will permit of the maximum amount of carbides in solution with the minimum amount of dissociation should be adopted. The maxim of successfully treating magnet steel is the "less you do to it and the more quickly it is done, the better."

Written Discussion:—By R. L. Sanford, Bureau of Standards, Washington.

For many years the production of good permanent magnets has been more or less of a trade secret, not so much in the sense that unusual processes are involved, but rather, that unusual precautions must be observed. It has long been a matter of common knowledge that originally good magnet steel can easily be injured in the process of manufacture into finished magnets. The technical literature on this subject, however, is very meager. The paper by Adams and Goeckler, backed as it is with practical experience, should prove to be very valuable in this connection.

I should like to comment on one or two points. First, in regard to magnetic testing of steel. The value of magnetic testing is coming to be more and more realized. It is true that other elements enter into the performance of finished magnets, but it is of first importance to be assured that the material of which they are to be made is of satisfactory quality. A good product cannot be made from inferior material. Magnetic testing has not been common in the past because of the unsatisfactory and complicated nature of the testing equipment available. Recent developments, however, have removed this objection and large quantities of material are now being furnished on the basis of specifications as to magnetic quality.

Second, with regard to the cobalt steels. The authors state that they

are difficult to work and their value is indeterminate. It is true that these steels are more difficult to work than the older magnet steels and much more expensive to manufacture. It is also true that magnets made according to designs suitable for the older types of magnet steel do not give a proportionate improvement in performance. On the other hand with proper design, it has been possible to achieve results with the new steels which have been hitherto impossible of accomplishment. It is to be hoped that American manufacturers will soon turn their attention to the production and utilization of steels of the K. S. type, which are already being used to a considerable extent in Europe.

The data given in the paper should be of very practical value and it is to be hoped that the authors will continue to make available the results of their experience.

Written Discussion:—By W. E. Ruder, Research Laboratory, General Electric Co., Schenectady, N. Y.

Scientific progress in the development of permanent magnet steels has been extremely slow, due mainly to the lack of definite standards of excellency for the metallurgist to work to. The extreme complication of composition presents in itself a difficult problem, but when this is added to the vagaries of the, as yet, not too well understood magnetic phenomena, it is not surprising that real progress has been slow. The authors of this paper have made a distinct contribution to the literature on the subject by calling more specific attention to the effect of "previous history" upon the quality of the finished magnet. From a practical point of view this information is most valuable, but it is also interesting to those who are trying to solve the riddle of the relationship between metallurgical structure and magnetic "quality." S. Evershed has called attention to the important effect of previous history on the quality of tungsten magnet steels, but evidently became so discouraged with the lack of knowledge of magnetic phenomena on the part of some metallurgists that he scorns the whole profession and its terms, and all but loses his valuable experimental data and deductions in a sea of words.

I like to picture magnetic hardness much the same as Jeffries and Archer have pictured mechanical hardness with the provision, however, that the "keying" particles must all be in a special kind of atomic dispersion, or combination, and to that extent magnetic hardness will follow mechanical hardness, but critical dispersion, the largest factor in mechanical hardness, has no relation to the magnetic hardness. Examples of such divergence between magnetic and mechanical hardness have been frequently cited. Magnetic quality is composed of two factors, B_r, the strength of field, and H_c, the force which maintains that field. The relative importance of these two factors has been much discussed, Mathews and Gumlich each suggesting a combination of the two to represent a measure of magnetic quality. This is of doubtful practical value, however, as they each have a variable significance depending upon the size, shape and use to which the magnet is to be put. My own inclination is to value H_c rather more highly than either of these two authors have indicated, because the value, B_r, may mean little

in the magnet as actually used, due to the demagnetization of the poles, which is greater the less the coercive force. This point is nicely illustrated by Gumlich.[1]

Mathews has shown (H. M. Howe Memorial lecture, 1925) that the retention of austenite is responsible for increased H_c values and Eversted also discusses the retention of austenite, but deplores it on account of the decrease in B_r. This increase in H_c is probably due to the greater solubility of gamma iron for carbon and may be the direct cause for the very high value of H_c in cobalt steels, the decrease in alpha iron being compensated for, in the value of B_r, by the greater saturation value of the cobaltic ferrite. This new point of view does not clarify the situation much, however, unless we can understand just how a solution of carbon in a non-magnetic atom can affect the retention of magnetism by a neighboring magnetic atom. Let us, then, go the whole way and assume that dispersed austenite is always present to some degree in hardened steel and is the *predominating* factor in producing magnetic hardness. We must assume, then, that the reversal of magnetism requires not a shift in electron orbits, but an actual reversal of the atom which reversal is hindered by the presence of contiguous austenitic atoms. This calls for an assumption of a combination, or better still, a phase equilibrium between ferrite and austenite, not yet recognized by the metallurgist. Mere solid solution of carbon—in alpha iron—cannot account for the high coercive force of magnet steels, for silicon up to 5 per cent has no effect upon the coercive force except, indirectly, to lower it, and its effect in distorting the iron lattice cannot be so much less than that produced by a very much smaller percentage of carbon. Likewise, gamma iron alone is ineffective, but Gumlich has shown that drastically cooled carbon steels have about as high a coercive force as the tungsten or chromium steels, but that their B_r values are very low. The function of the added alloys is then merely to raise B_r by keeping the carbon in solution and so retaining a sufficient quantity of austenite, and freeing the rest of the iron as magnetic ferrite. That the carbide forming elements, such as manganese, chromium, tungsten and molybdenum, found most effective in producing high coercive force with a reasonable retentivity, all "have strong austenitic characteristics," to quote from Mathews' paper, tends to support this view.

Of course any particles of carbide precipitated by improper heat treatment, no matter how small, lose their position in the atomic arrangement and become only so much extraneous material.

If B_r is a direct function of the alpha iron present and H_c of the dissolved carbon, then a heat treatment which will liberate carbides will reduce H_c and increase B_r, as shown in Table X. It will be noted, however, that at 1400 degrees Fahr. a reduction in both H_c and B_r takes place. This can only mean decomposition of carbides whereby the chromium enters the ferrite and reduces its magnetism in proportion. That this does not occur in tungsten steels (Table XI) means that while agglomeration takes place there is no actual decomposition, as the authors have pointed out.

The effect of air quenching far above the critical range, while less harmful than slow cooling in any case, is still not sufficient to restore the material

[1] *Testing*, Vol. 1, March, 1924, p. 221.

to the quenched from the "as-rolled" condition. It would be interesting to know whether the authors ever tried the very high temperature (2265 degrees Fahr.) suggested by Evershed as a restorer of magnets spoiled by heating, or the treatment suggested by him for curing the evil effects of overheated steel. The experience of some magnet makers indicate that a normalizing treatment which will not decarburize or decompose carbides will entirely restore quality and theoretically it seems that it should.

Written Discussion:—By R. L. Dowdell, University of Minnesota, Minneapolis, Minn.

The most interesting contribution of Mr. Adams and Mr. Goeckler contains very valuable and useful information concerning the thermal treatment of permanent magnet steels.

The data presented in Tables II, III, V, VII, and VIII on tungsten, chromium, and low cobalt-chromium magnet steels, shows almost without exception that if complex alloy steels of the same section are water and oil-quenched from the same temperature, the pieces quenched in oil will be less magnetic (lower value of B_r) due to the retention of either austenite or troostite.

The coercive force after oil quenching these steels is greater, thus showing that they contain more austenite and not troostite, because when troostite appears on tempering a magnet steel both the coercive force and the residual induction drop to low values. Of course it is possible that the arrangement of the martensite and austenite is different in oil and water quenching without changing the relative amounts.

Dr. Mathews[1] has summarized considerable evidence from experiments on density, volume changes in tempering, magnetic and X-ray tests, and microstructure indicating that more austenite is retained by oil quenching these alloys than by water quenching. This statement that oil quenching produces more austenite still requires explanation, but considerable evidence points toward it.

The values of both B_r and H_c for a chromium steel shown in Table XII decrease as the time of holding at the quenching temperature is increased, which would seem to indicate that the grain size of this steel increased and caused the lowering of the values even though more of the carbides were retained in solution.

As the authors have stated, it appears from their work and from the work of Murakami, that in chromium steels the dissociation of carbides increases with holding at a high temperature or for a long time and that slow cooling from temperatures above the critical point allows these dissociated carbides to partly associate. However, I would think that this dissociation phenomenon could largely be counteracted by the multiple quenching of the previously normalized or annealed bars, after holding very short times from temperatures above A_c but not to exceed about 1580 degrees Fahr. This treatment may not be a commercial treatment but from the standpoint of

[1]Dr. J. A. Mathews, Second Annual Henry Marion Howe Memorial Lecture, delivered at the New York Meeting of the American Institute of Mining and Metallurgical Engineers, Feb. 16, 1925.

grain refinement and the elimination of the spheroidized carbides, it may equal the magnetic values obtained by hardening the "as-rolled" bars.

I should like to ask the authors if they have tried any multiple quenching experiments?

Authors' Reply to Discussion

In reply to Mr. Sanford, the authors wish to make it clear that they do not mean to imply that the cobalt magnet steels have little merit, but only that up to the present time they have failed to be widely used due, as Mr. Sanford points out, to lack of knowledge respecting the necessary design to take advantage of their high magnetic values. So far, present results seem to indicate that in order to use their high magnetic values quite different designs are necessary from those used with ordinary magnet steels. It may be found later that they are very susceptible to small changes in design and size. This may mitigate against their adoption, since manufacturers of machines are compelled to make changes from time to time to meet changing conditions, in which case it may be necessary to make very considerable changes in the design of the permanent magnet, if a cobalt magnet steel is being used. Future development and experience can only answer this question.

Mr. Dowdell and Mr. Ruder both refer to Dr. Mathew's paper on "Austenite and Austentic Steels." It is still questionable as to whether more austenite is retained in these steels by an oil quench than a water quench, although the evidence is certainly strong for the adoption of such a view. However, the authors feel that undue stress is being laid upon this phase as affecting the phenomena they are discussing. They would point out that the adoption of the retained austenite theory is in no way incompatible with their theory of the carbide spheroidization since such spheroidization retards the dispersion of the carbides in the subsequent austenitic solution, thus possibly effecting the amount of retained austenite upon subsequent quenching. The point here is that if the amount of retained austenite is the predominating factor effecting coercive force the spheroidization of the carbides effects the amount retained.

Further, the authors wish to point out that in Mr. E. C. Bain's paper in the July TRANSACTIONS for 1925, it is stated that all austenite is decomposed above approximately 500 degrees Fahr., for a chromium magnet steel containing 2.6 per cent. Chromium magnet steel drawn at this temperature retains considerable coercive force.

In answer to Mr. Dowdell's question respecting multiple quenching, the authors can state that they have quenched magnets up to as many as three times and usually found decreasing values after the initial quench. Mr. Dowdell's point is well taken from the point of view that such a procedure might readily be thought to assist the dispersion of the carbides, but it must be remembered that in heating up to the critical point some respheroidization is probably occurring, thus counteracting the dispersion obtaining from the previous partial solution from the original spheroids present which must necessarily be slight, due to the low mobility of chromium carbides.

In answer to Mr. Ruder's question as to our experience with high air

(Continued on Page 213)

APPLICATION OF THE MATHEMATICS OF PROBABILITY TO EXPERIMENTAL DATA AS A BASIS FOR APPROPRIATE CHOICE OF FERROUS MATERIALS

By B. D. Saklatwalla and H. T. Chandler

Abstract

The number of alloy steels which are now in use make the problem of selecting the most suitable alloy steel a perplexing one. In this paper the authors suggest a method of reasoning which should be of practical value in solving this problem. The "law of error" and "the law of frequency" are considered.

Probability curves are given in which the Brinell hardnesses are plotted against the frequency number of castings in foundry practice. This graphic method of representation gives more satisfactory results than mere averages of numbers.

FOLLOWING the demand created by the rapid strides and complexity in design of modern mechanical equipment, a variety of ferrous alloys have come into existence within the last decade or two. This has constituted our modern metallurgy, particularly that of alloy steels. This metallurgy has, in some measure, overstepped the existing demand, inasmuch as for every requirement a number of alloys have been brought forth, making the question of selection of the right alloy an apparently perplexing one. It is the purpose of the following remarks to draw attention, in only an introductory manner, to a method of reasoning, which may be of considerable practical utility in meeting this perplexing situation.

The science of metals has been developed to a high degree of exactitude and our knowledge of their state immeasurably widened. Ferrous metallurgy especially has been a fruitful field of research, and even of scientific speculation, with better and more exact knowledge of the effect of various elements and constituents occurring in steels. We must, however, bear in mind that such scientific knowledge of metals is derived under regulated and exact laboratory conditions, and, therefore, we must

A paper presented before the Cleveland Convention of the Society, September, 1925. Of the authors, B. D. Saklatwalla, is vice-president and H. T. Chandler is metallurgical engineer with the Vanadium Corporation of America, Bridgeville, Pa.

distinguish clearly between the science of metals and the science of applied metallurgy. The latter, undoubtedly, still bears the category of an art, as the skill with which the processes are carried out must influence the products obtained. With the progress of the pure science of metals we have learned, however, to practice this art on a more scientific basis. With the vast accumulation of coordinated metallurgical data and the systematic correlation of composition, properties, process of manufacture, etc., to actual service, we are justified in speaking of a "science" of applied metallurgy.

With the term "science" the average mind associates a degree of exactitude, infallibly coordinating cause and effect. However, the "sciences," as we term them, are not bound by such measure of exactitude. If we survey the realm of the "sciences," we find that, commencing with mathematics, the most exact of them all, through physics, astronomy, and chemistry, we come to the so-called "natural-history" sciences, covered by the generic term, "biology," and then to the political and sociological sciences where the degree of exactitude of correlation between cause and effect is quite of a diminished order. This diminishing degree of exactitude is brought about by the large number of varying, uncontrollable, accompanying circumstances under which the correlated data are obtained. Thus, while we can readily see the unvarying exactitude of a mathematical formula or of the laws of gravitation or thermo-dynamics, we can appreciate the possibilities of varying results in biology, and much more so in sociological sciences. To keep the conditions of a biological phenomenon constant to the extent of a physical laboratory experiment would hardly be thinkable. In other words, mathematical and physical data are influenced by no degree of variability, whereas biological and sociological data are influenced by a high degree of variability.

The science of applied metallurgy may be taken to be of the same order as that, for instance, of biology, with the attendant degree of variation of its data. It is, therefore, perfectly logical to apply the methods of research and reasoning to applied metallurgy that have given results in the older sciences of biology or sociology. The most useful method, under such circumstances, has been the application of the mathematics of probability to the accumulated experimental data.

The well-known method of representing results of phenomena under change of conditions by means of a straight-line curve, coordinating the results and conditions plotted as ordinate and abscissa, which afforded wonderful information when applied to the sciences of less variant degree, fails completely when applied to a highly variant-degree science, such as that of applied metallurgy. For instance, if the values of the reduction of area of a number of specimens of a steel are plotted in a coordinating diagram against drawing temperatures, the variation in reduction of area among the different specimens at the same temperature may be much greater than the variation suffered on the same specimen by alteration of the drawing temperature. It is, therefore, readily to be seen that, in such a case, a straight-line diagram will give information erroneous, if any, as to our expectancy of obtaining the desired reduction of area from the several specimens. If, however, the specimens were plotted on a probability curve, following the procedure of, for instance, biological science, we would obtain more tangible and more practical information.

To more clearly elucidate the analogy of biological representation, we can take the example of the probability of obtaining a certain length of stalks in a corn field. The frequency curve,[1] Fig. 1, shows clearly the result of tabulation of measurements of a certain number of stalks at random. The length of the stalks may depend on such varying factors as soil, seed, insect ravages, drainage, etc., just as steel specimens of same composition would vary according to their different life-history, constituted by melting, casting, rolling and fabricating practice.

This curve is plotted from the data contained in Table I, where the height of stalk in feet is shown along the horizontal line and the number of stalks of various heights in groups are plotted in the vertical direction.

From data of this kind, by mathematical deduction we can derive a general curve, giving us a relation between the extent of the deviations and the frequency with which they occur, expressing the "law of error." Reverting to the example of the corn stalks, Fig. 1, and reviewing many similar ones, we see that we can deduce the law that both chance and natural phenomena tend to fluctuate about a normal. The large majority

[1]Taken from Willford I. King's "The Elements of Statistical Method," 1923, page 109.

of items are usually grouped near the center line or node, and, as the distance from the node becomes greater, the items become rapidly fewer in number. In natural phenomena, a maxi-

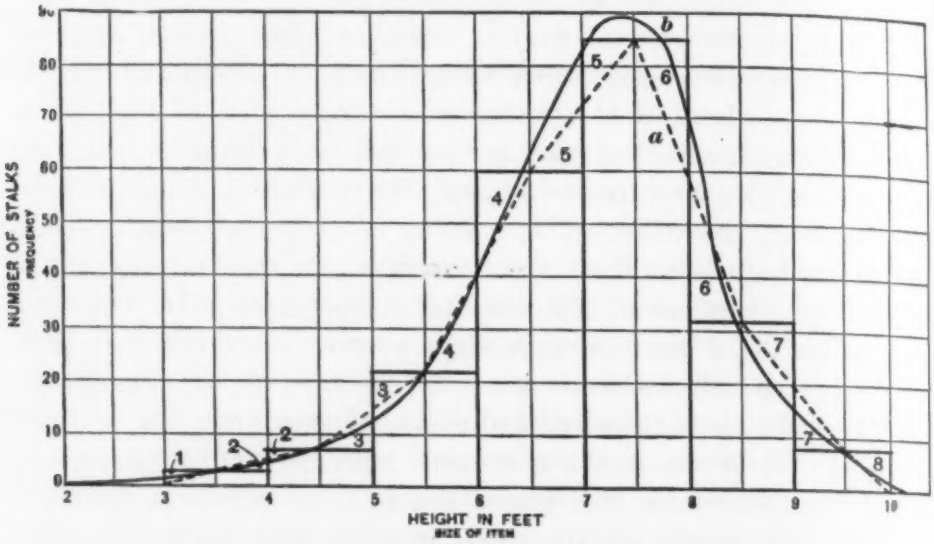


Fig. 1—Frequency Curve of Corn Stalks Selected at Random.

mum deviation may be approximately determined beyond which no items occur. This law was discovered by Quetelet and is the basis upon which a large part of the science of statistics is built.

A theorem of great importance in the theory of probability

Table I

Height in Feet (Size of Item)	No. of Stalks (Frequency).
m	f
3–4	3
4–5	7
5–6	22
6–7	60
7–8	85
8–9	32
9–10	8
	n = 217

itself, and in its application to practical problems, is the "law of error," which may not be out of place here to discuss very briefly.

Suppose an experiment to be such that the chance of success is always "p" and of failure "q," so that $p + q = 1$; and then let the experiment be repeated "n" times, and consider the chance of obtaining "r" successes and $n - r$ failures, then the chances

of 0, 1, 2, - - - - n successes can be shown to be the successive terms of the binominal expansion:

$$1 = (q + p)^n = q^n + n.q^{n-1} p + \text{ - - - - } + C_r . q^{n-r} p^r + n q p^{n-1} + p^n$$

which may be finally expressed as:

$$y = \frac{1}{C \sqrt{\pi}} e^{\frac{-x2}{c2}}$$

which equation means that, when any n fold experiment is made, the number of successes shall be x in excess of p n, where p is the chance of success in a single experiment.

This mathematical deduction of the "law of error," by plausible reasoning, gives in practice approximately the proportion of accidental errors in any appropriate interval, and can be graphically plotted, as shown[2] in Fig. 2.

The "law of error" is a relation between the extent of a deviation and the frequency with which it occurs. Every "law of error" is a "law of frequency," the converse of which is not always true. However, a relation between the two exists, so that, with sufficient data rightly selected, a "frequency curve" will closely approximate a true "probability curve."

The application of this method of graphic representation to applied metallurgy would appear to be logical, and such application has proved of merit in actual practice. In applied metallurgy we are concerned with the number of successes or failures derived under usual commercial conditions, and, therefore, any method which gives a tangible value of our expectancy of favorable or unfavorable results is certainly much more valuable, from a practical standpoint, than any method which may give us knowledge, however positive, of the qualifications of material, under controlled laboratory conditions only. We are more and more beginning to realize the inadequateness of the application of our laboratory tests to service results, and are looking for means which will tell us with what probability we will get the material we are searching for, adaptable to a certain engineering purpose. This is exactly what the mathematical theory of probability purports to do. Probability has been defined by Ber-

[2]Taken from Bowley's "Elements of Statistics."

nouilli as the measure of the strength of our expectancy of a future event. Is this not precisely what the manufacturer and heat-treater of steel desires to know? Are they not interested in finding what precentage of the material of one class will give the properties in service, which are attributed to that class, and what will be the magnitude of the variations from these class-properties? The same line of reasoning affords them the recommenda-

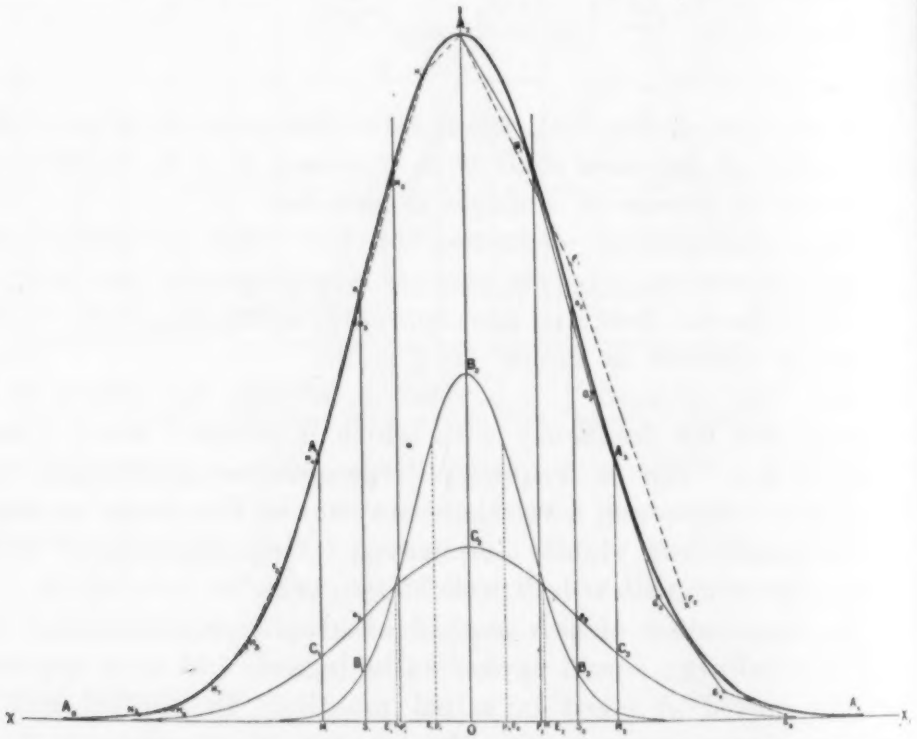


Fig. 2—Graphical Representation of the Mathematical Deduction of the "Law of Error."

tion of one class over another. The two classes or types of steels may have similar specifications as derived from laboratory tests. but their probability curves may show very different results as to their chances or percentages of failure and success in actual service under all existing commercial conditions. As an extreme case, we may cite the fact that it is possible to obtain with carbon steel, under laboratory conditions, physical properties fully equal to alloy steels, but actual experience has proved that it would be disastrous to substitute them for service conditions, and, consequently, relying on experience alone, we have let alloy steels capture the fields of high duty service. Experience has taught us that our *chances* of obtaining the service results with alloy

steels are so much greater than with carbon steels, and similarly our experience has been that with one class of alloy steels with a given service our *chances* of success are much greater than with another class, irrespective of the chemical composition and physical properties set under laboratory conditions as criteria of the class. If we had for the given service correlated data over a period of time regarding the use of carbon, and also of alloy steels, and plotted these data on probability curves, we would

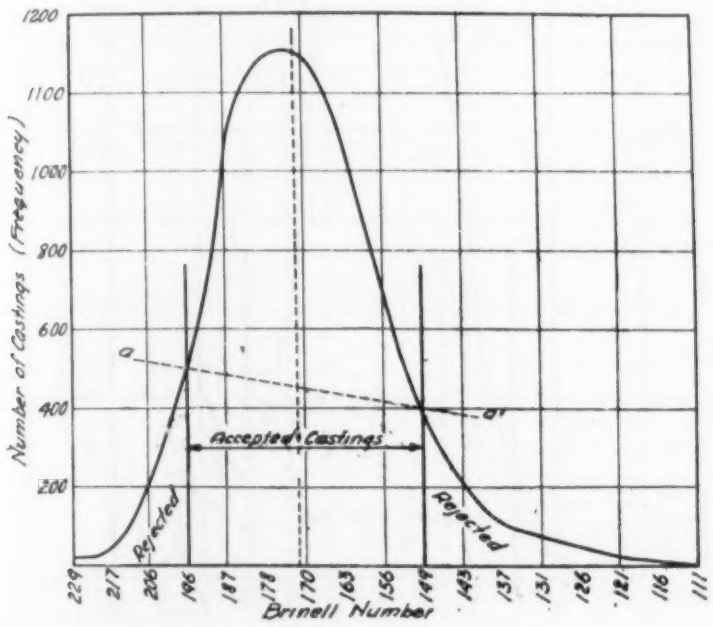


Fig. 3—Probability Curve—Brinell Hardness of Fly Wheels—January, 1924, to January, 1925—No. of Tests 7160.

have very soon found out that we obtained much more consistent results with less deviation from the standard in the case of alloy than of carbon steels. The probability curve would tell practically the entire story and show what degree of certainty of success we may obtain in similar service from the one class or the other.

As a practical example of the clarity with which the probability curve tells its story, we may examine Figs. 3 and 4 in which the Brinell hardnesses are plotted against the frequency number of castings in foundry practice. Fig. 3 represents flywheels cast during a period of one year, January, 1924, to January, 1925, the number of specimens tested being 7160. The curve,

at a glance, gives the suitability of the particular mixture and practice for the purpose.

In Fig. 4 is graphically represented a fly-wheel casting practice similar to that shown in Fig. 3. The tests were run in January, 1925, and represented determinations on 1551 pieces. By comparison with Fig. 3, it can be seen that the mixture and practice represented by the fly-wheels in Fig. 4 gave more consistently

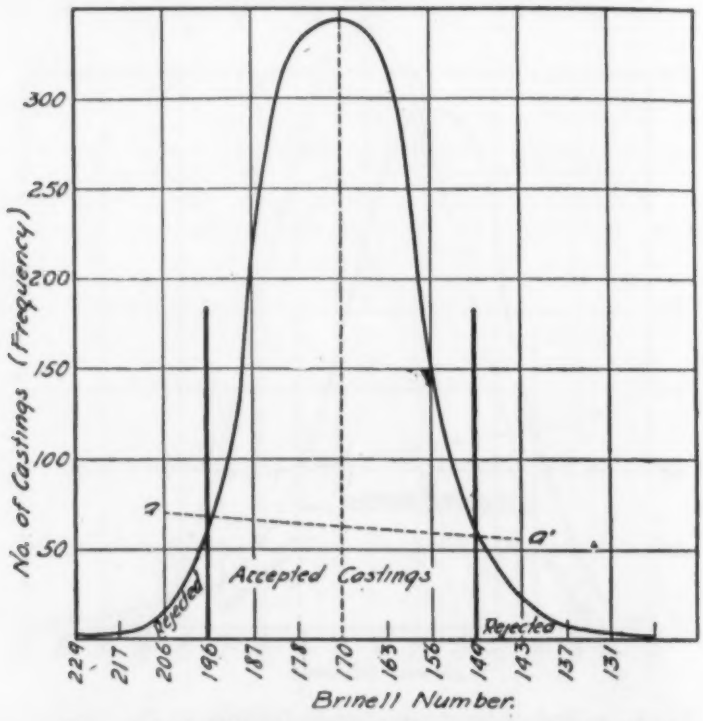


Fig. 4—Probability Curve—Brinell Hardness of Fly Wheels—January, 1925—No. of Tests 1551.

good results than those represented in Fig. 3. The percentage of rejection in Fig. 4 amounted to only about 8.

Fig. 5 represents graphically the practice on fly-wheels during the subsequent month of February, 1925, in the same foundry. It will be seen that certain definite influences must have arisen, tending towards production of soft iron. Even in the accepted range, the characteristics of the curve are entirely different from that in Fig 4, and appear to form an outline composed of superimposition of separate curves, as indicated by dotted lines in Fig. 4, probably indicating separate causes tending to produce separate effects, all culminating in the production of softer iron.

From a little study of the curves and Brinell numbers given in Figs. 3 to 5, it can readily be seen that this graphic method of representation gives a very different idea and tells a very different story than mere averages of the numbers would give. There is the possibility that, with the same average Brinell hardness on the fly-wheel operation over two different periods of time, the practice, and, consequently, the number of accepted castings

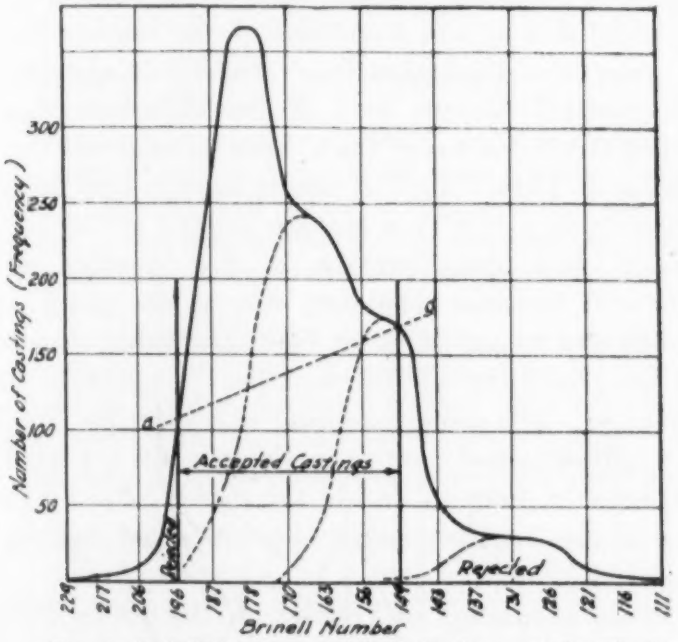


Fig. 5—Probability Curve—Brinell Hardness of Fly Wheels—February, 1925—No. of Tests 1837.

and financial returns, can be very different, without being indicated in the least degree by the averages. In this connection, it is significant to know that the operation represented by Fig. 4 in January and by Fig. 5 in February, had reached, during the subsequent month of March, 1925, such proportions in rejections as to warrant it to be discontinued to thoroughly remedy production conditions. The probability curve could have foretold the impending ominous condition.

What has been elucidated above, by the example of fly-wheel castings, is true of any other ferrous products. This method helps us not only in the selection of a certain composition or a certain class, but also helps us towards the determination of an adequate source for procurement of engineering materials. The chances with which we will get the desired service results from

the product are not only dependent on what we may term assurance of composition in melting and the sensitiveness and susceptibility of the composition to adequately suffer heat and mechanical treatment, but also upon the factors which may adversely affect the qualities of the composition during its manufacture, brought about not only by the quality of the raw materials used but also by the care or negligence and skill displayed by the personnel during melting, casting and fabricating processes. We have all puzzled over the definition of the elusive term "brand" in steel practice. Undoubtedly, "brand" is constituted by the above enumerated factors, and, if the different "brands" from service results on the same work were plotted on the same basis of reasoning as Figs. 3 to 5, it might have helped to remove some of the elusiveness and give a clearer picture of the idea "brand."

Having given consideration to the question of "brand," there may still be some perplexity due to the possibility of selection of different types of steel from the same source or brand. Further, the possibility of different heat treatments for the same type may arise. The same reasoning and plotting of a large number of actually attained results in practice on a probability curve will, undoubtedly, help to decide the dependence of the one type of steel or of one heat treatment over the other for the particular service.

One great advantage of relying on the probability curve for an answer in selecting source, type, and treatment of steel is the fact that the curve is constructed from actual experimental or service data, and, therefore, comprehensively includes all possible varying factors, and must, therefore, prove conclusive for future practical purposes. Undoubtedly, we have already gone far enough in our use and exploitation of special steels to furnish sufficient data for a fair criterion of the evaluation of such steels, and it should, undoubtedly, be our effort, in the future, to collect all data which will enable us to establish criteria for our materials from the "probability" standpoint, that is, the standpoint of reliability in service.

This method of graphically plotting data is applicable not only to the qualifications of finished material but also to the factors governing the processes producing materials. The controllable physical and chemical factors in most metallurgical processes are rather scant and the more variable and uncontrollable

these factors are in a process the more adaptable is the probability method to it. As process naturally establishes the qualifications of the product, a more dependable knowledge of the process undoubtedly tends towards improvement of the product. We can, therefore, see that the ramifications of the probability method in applied metallurgy can be many and of real practical and commercial importance, and it is for this reason that this vast subject matter could be dealt with here in only an introductory manner.

Written Discussion:—By E. S. Taylerson, engineer of tests, American Sheet and Tin Plate Co., Pittsburgh.

This paper discusses a very useful method of expressing engineering data. In applying this method, recently, to extensive production data, we have found that the bell-shaped curve discussed by Messrs. Saklatwalla and Chandler is very useful. The actual measurements used for the abscissae and ordinates, are quite important, especially if we want to compare one group of data with another similar group.

We can plot a smooth bell-shaped curve only where we have a large number of data. Where we have fewer data, it is usually preferable to plot a step curve, as illustrated in Fig. 1 of the author's paper. This step curve is easier to explain to a non-technical man than the bell-shaped curve. Further, if

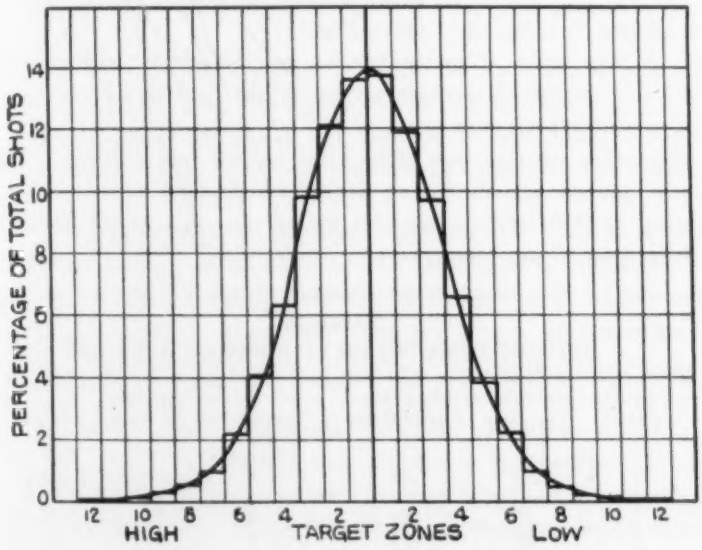


Fig. A—Bell-shaped and Step Curves Plotted from Data in Table A of this Discussion.

we express our ordinates as percentage of the total number of results, the ordinates being 100 per cent high, we can easily explain that the total area of the curve is equal to one strip 100 per cent high. In other words, if the test results of all the specimens were of the same value (the same Brinell number, for instance) we would have only one strip 100 per cent high. If, as is usual,

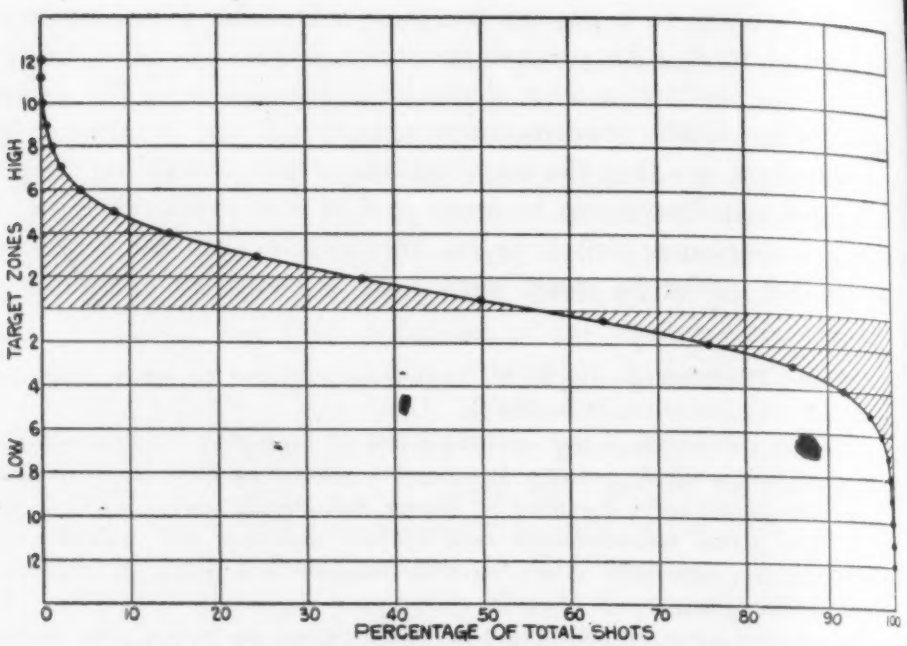


Fig. B—O-G Curve Plotted from Data in Table A of this Discussion.

deviation occurs in the results, we can take that strip originally 100 per cent long and cut it up into sections, each section representing that percentage of the total number of results falling in that particular class. We then get the step curve shown in Fig. A. (See Fig. 1).[1]

By using this scale of ordinates we are justified (provided the abscissae are similar) in comparing various series of data. The curves all being to the same scale are of equal area.

For abscissae, we can use either the actual test values (such as Brinell hardness), or percentage deviation from the desired value. For instance, if we are aiming at 200 Brinell, we can figure the percentage deviation and plot the results in percentage classes.

Table A
Vertical Distribution of Shots on a Target

Target Zone	Number of Hits	Per Cent of Total Hits Per Zone	Per Cent of Total Hits Cumulative	Target Zone	Number of Hits	Per Cent of Total Hits Per Zone	Per Cent of Total Hits Cumulative
Top				*Center*			
12	1	.07	.07	1	208	13.76	63.74
11	1	.07	.14	2	180	11.91	75.65
10	2	.13	.27	3	146	9.66	85.31
9	4	.27	.54	4	100	6.62	91.93
8	8	.53	1.07	5	59	3.90	95.83
7	14	.93	2.00	6	34	2.25	98.08
6	32	2.12	4.12	7	15	.99	99.07
5	61	4.04	8.16	8	7	.46	99.53
4	96	6.35	14.51	9	3	.20	99.73
3	148	9.80	24.31	10	2	.13	99.86
2	182	12.04	36.35	11	1	.07	99.93
1	206	13.63	49.98	12	1	.07	100.00
Center				*Bottom*			

[1]Taken from W. L. Hart, *Journal*, American Water Works Association, November, 1920.

The selection of the magnitude of these percentage classes is quite important. If the classes are too small or we have too few results, we get a very erratic curve with reentrant steps. If we increase the range of the classes we get a reasonably smooth curve. In this respect, each specific problem demands consideration on its own merits.

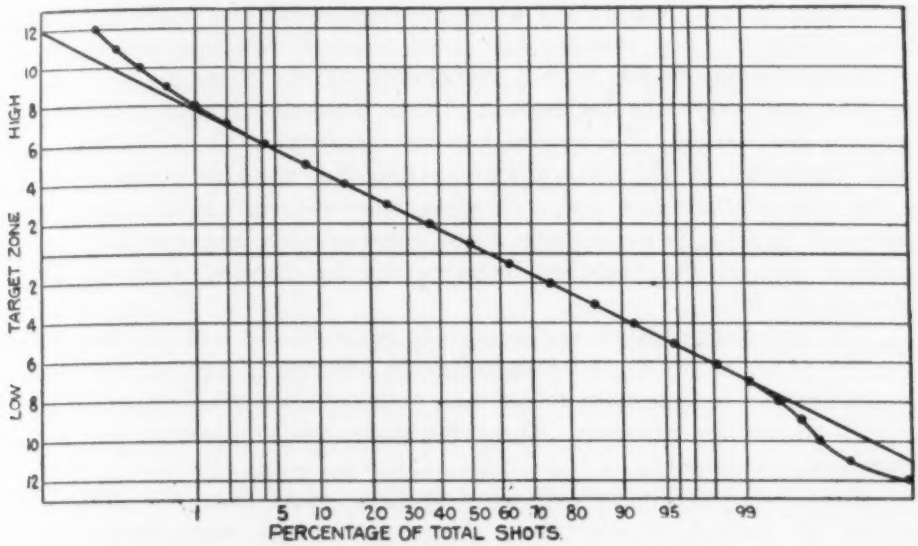


Fig. C—Data in Table A of this Discussion Plotted on Probability Paper.

Several arrangements of coordinates for the bell-shaped curve are thus possible:—

We can use the actual number of tests for ordinates and actual data, such as Brinell numbers for abscissae, as in the author's Fig. 3, 4, and 5. The area of this curve depends on the number of tests, and therefore, we are not justified in comparing different sets of data unless the number of tests is equal.

We can use percentage of the total number of tests for ordinates and actual data for abscissae, as in Fig. A. If this data is expressed in arbitrary units, which do not have a linear relation to the property under consideration, the curve may be seriously distorted from the shape of a normal probability curve. This may be true in the case of Brinell hardness numbers, as the Brinell number does not of necessity bear a simple linear relation to the actual "hardness," provided that "hardness" can be definitely defined.

We can go a step further and use, as above, the percentage of total tests for ordinates and percentage deviation for abscissae. The percentage deviation can be either from the mean or preferably from the particular value desired.

Another type of curve, preferred by some, is a curve of the O-G type, shown in Fig. B, which is plotted from the same data as Fig. A. We use 100 divisions, representing percentage as abscissae, and any convenient ordinate scale. It is necessary to figure the number of tests in cumulative percentage distribution for this type of curve, as in columns 4 and 8 of the table, which is also necessary if "probability paper" is used, as discussed later. If there were no variation whatever the O-G curve would be a horizontal

straight line. The shaded areas in Fig. B represent graphically the deviation from the normal.

Where we intend solely to present the data to technical readers, it is simpler to use an especially ruled coordinate paper, (invented by Allen Hazen) known as probability paper, which is figured from the theoretical normal probability curve given in the authors' paper. This is shown in simplified form in Fig. C. Any straight line ruled across it will represent results distributed according to this normal probability curve. If the deviation is small the line approaches the horizontal. As the deviation increases this line approaches the vertical. The graduations are symmetrical about the 50 per cent axis. Referring to Fig. C it will be noticed that we have a wide open scale at the ends of the figure and a closely compressed scale in the center. This method of plotting is particularly useful when one has very few data. A preliminary idea of the probable deviation can be obtained from the general trend of the line.

The probability law is mathematical, and does not consider the personal equation which enters into all manufacturing processes. Thus in plotting data by this method it is usually found that points deviate from the straight line at each end of the diagram. These deviations are of great interest from a production standpoint.[2]

Many industrial investigations yield data which seem hopelessly inconsistent. If instead of discarding these results they were studied by the statistical method, it is believed that exceptionally useful conclusions could often be drawn.

Any of the three methods of plotting, shown in Figs. A, B and C, can be employed, the choice largely depending on the particular use to be made of the diagrams.

Of the many "deviation measures" mentioned in the discussion, the easiest to figure is the average deviation from the normal. This is especially true if tabulating machines are used for compiling the data. The cards are punched and sorted electrically into classes. After tabulation the average deviation from the normal is easily figured from the tabulating machine totals by dividing them by the number of cards involved.

Written Discussion:—By J. S. Vanick, The International Nickel Co., N. Y.

In this discussion of error, probability, laboratory and service tests, it is not unlikely that the picture may be distorted by the inter-relation of its components. Perhaps a quick and easy classification would consist of grouping the laws of error with the laboratory, and the laws of probability with service conditions. In these groupings the discussion which the authors advance largely involves the laws of probability or chance rather than those of error or observation. One method concentrates upon the material; the second upon the part or object under test.

I do not agree on one point, as stated, that laboratory tests are inadequate for the prediction of the application of a metal to a certain engineering purpose. More often it is the inapplicability of the test to the

[2]See Haskell's Graphic Charts in Business, Chapter XVII, for a fuller discussion of probability paper.

question at issue, or the misinterpretation of test results that destroy the applicability. In most metallurgical developments the laboratory tests precede the application of the metal to service, and subsequently, frequent laboratory tests maintain the quality of the product specified. While laboratory data are not wholly adequate to establish the service record of a material, they go far toward predicting its "probable" behavior if the stresses encountered are not too involved or complex. Commercial or service applications usually involve compound events, each of which introduces its special element of chance, while controlled laboratory conditions serve to eliminate the chances. Laboratory results are only applicable to service results as long as they duplicate the conditions of service. A laboratory investigation of the properties of a material is therefore confined to those factors which are fundamental or predominant in the commercial application. There are well-known and well understood relations between the classified data of the laboratory and the simple stresses encountered in service. These relations can be correlated and the probable merit of the material predicted. This prediction naturally precedes the evaluation of the ultimate service record.

In metallurgical developments, the service test must remain an individual method, adaptable only to the survey of a specific object with its design and "method of test" or other service conditions introducing compound variables which are absent in the laboratory test specimen. Thus, the service test speaks an isolated tongue and its probability curve will serve to supplement the laboratory test in improving the record of a material which has already been chosen, while the laboratory test, under standardized and closely controlled conditions, makes the test results speak a universal language for the material under test. A good example of this fact appears in the authors' data citing the "probability curve" of successful castings against the Brinell hardness test.

The relation of materials to their service records is undoubtedly kept "in mind" by manufacturers and consumers, if not in the form of graphs or mathematical curves. The interesting "probability curve" methods which the authors describe should be recommended where careful records of the development of some special object are necessary for its improvement.

Written Discussion:—By Karl Daeves, Duesseldorf, Germany.

The paper of Saklatwalla and Chandler refers to a research method which in Germany we call "Grosszahlforschung" (large number research), as it represents the application of the "law of large numbers" to the field of industrial research. It is in use at the research departments and laboratories and has replaced to a large extent the hitherto prevailing methods, which are more adapted to the purposes of abstract science.

In completion and in addition to the valuable examples given by Saklatwalla and Chandler a few more applications of an interesting feature may be cited in the following:

The frequency curves given by Saklatwalla and Chandler in Figs. 3 and 5 do not only show the accommodation of production to the required conditions, as the authors claim for, but also elucidate that the range Brinell No. 149-196 is too small for the process of manufacture. Assumed further, a steel

consumer would demand other ranges besides that mentioned above, e.g. from No. 158-187, we would be able, when using such curves as shown in Fig. 1, to deduct immediately from the ratio of the areas abcd + efgh to the total area of the old frequency curve acdghf, how much higher the percentage of the rejected parts will be and consequently how much higher the price is to be fixed. Thus the correlation between tolerance and price often searched for, is given at once.

Experiments have frequently been made to calculate the values of strength of steel from the analysis of such steel. The results, however, are widely divergent. The large number research uses the following methods:

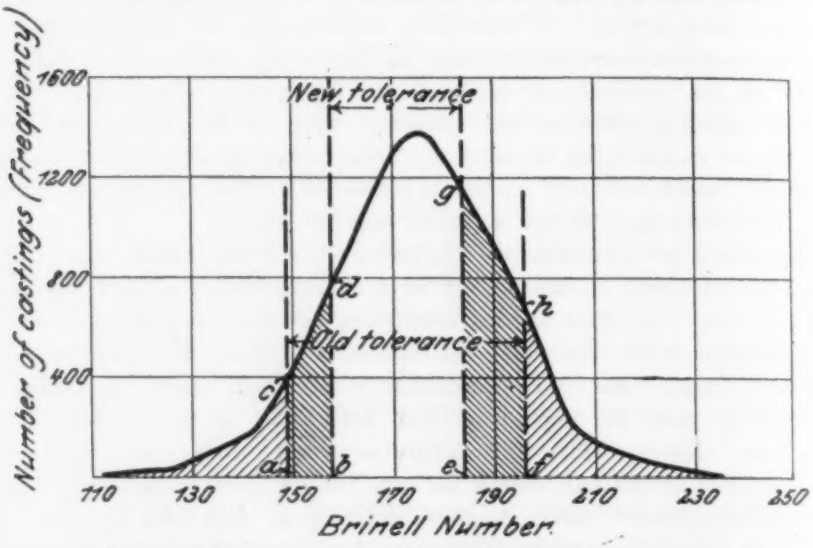


Fig. 1—Calculation of Prices when New Tolerances are Given.

Of a large number of steels containing 0.06-0.15 per cent carbon the values of strength have been plotted into a coordinating diagram according to the frequency with which they occur. By doing so a frequency curve of the strength of steels with an average carbon content of 0.1 per cent has been obtained. In the same way another group of steels containing 0.16 to 0.25 per cent carbon—showing an average carbon content of about 0.2 per cent, has been plotted, and so on. The maxima of these curves represent the values of strength to be normally expected for the respective carbon contents.

If these standard values of strength are then plotted in a diagram against the carbon content, we obtain the function between carbon content and strength, normally found as shown in the Fig. 2 of this discussion. The two dotted curves represent the variations or "errors" highly deviating here, owing in that particular case to the large number of different plants having furnished the steels.

With this evaluation the other chemical components could be neglected because the number of tests evaluated has been so large that in each curve rather the same number of test pieces containing more and less manganese, much and little phosphorus, sulphur, etc., have been found. All the other components with exception of carbon are therefore distributed at random and the

correlation is valid for a normal content of elements generally concurring with the different carbon content. For the practician, however, this very correlation is much more important than perhaps the influence of increasing carbon content upon the strength of chemically pure iron.

If we are investigating the influence of manganese, phosphorus or sulphur on the strength, we only must trace frequency curves with different manganese contents etc., by using the same data. In these cases the carbon is then distributed at random in the same manner as the other components and only the in-

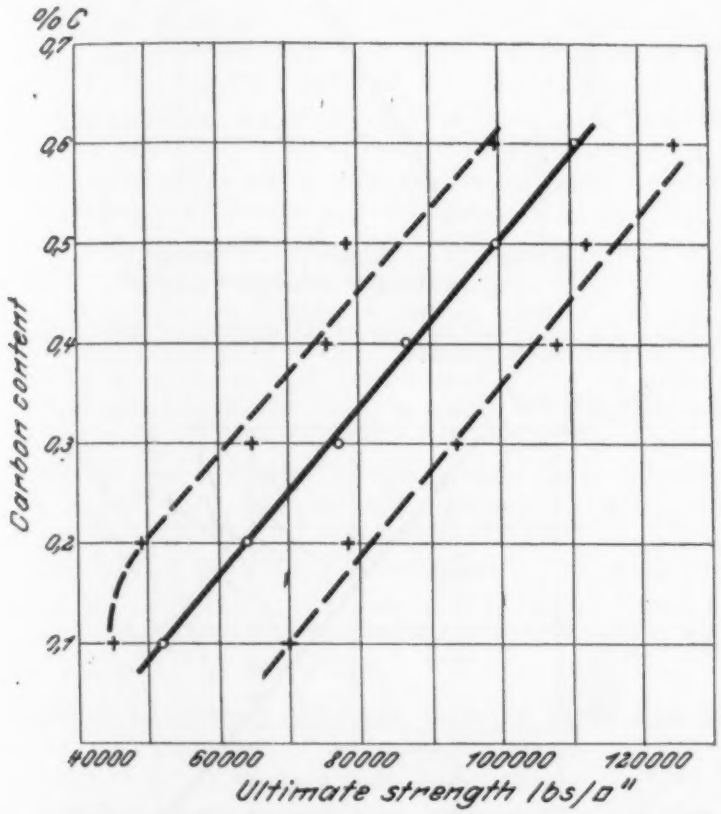


Fig. 2—Normal Influence of Carbon Content on the Ultimate Strength of Open-Hearth Steel.

fluence of the manganese content become distinctly visible. Those results are represented in Fig. 3 of this discussion. It will be seen that 0.1 per cent of manganese increases the ultimate strength for about 1700 pounds per square inch.

It is evident that with this method we are also able to find the influence of the casting and rolling temperatures or of any other factor on the strength of the final product, or to determine the percentage of rejections. Such an example is given in Fig. 4 of this discussion. It will be seen how failures are decreasing with increasing rolling temperature. It should, however, be stated, that the points of all these curves are derived from the frequency curves the maxima of which these points are representing.

The large number research is a method of making evident in figures the

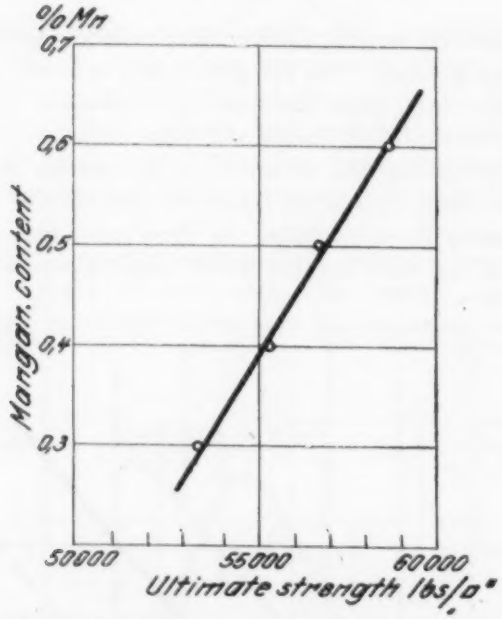


Fig. 3—Normal Influence of the Manganese Content on the Ultimate Strength.

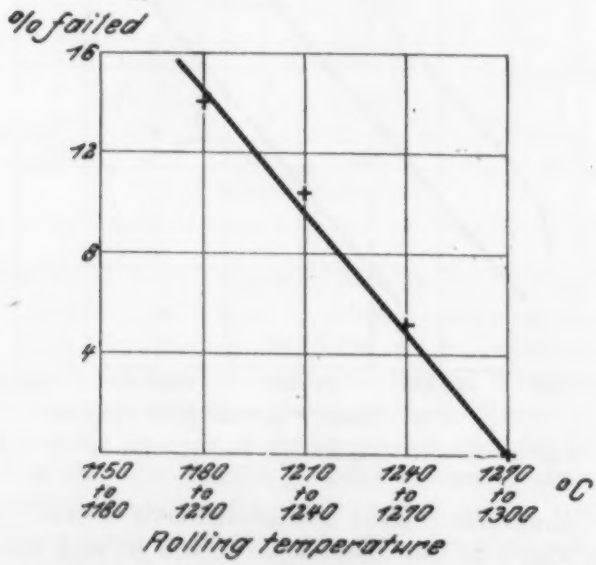


Fig. 4—Influence of the Rolling Temperature on the Percentage of Failed Pipes.

always highly appreciated experience. It should be applied, as all statistical work, only by men who are very intimate with the working methods to be examined, otherwise they will come to false conclusions concerning cause and effect.

On the other hand it is the very feature and a practical advantage of the large number research that it tries not so much to find out the *causes* of failures and unsatisfactory results but rather the *remedies*. I have often perceived by means of the large number research that for instance higher casting

temperature has a favorable influence on the final product, without having been able to find in the moment the reason for that phenomenon. Subsequently, instructions have been given to cast at higher temperatures and always the same successful results have been obtained, although the theoretical reason for that fact was discovered only later or not at all. In that way I succeeded in finding the most favorable conditions for all working methods examined and I was able to minimize the rejections (defects on seamless tubes, blisters and bad surface of tin plates, manufacture of well weldable material etc.). This evaluation method too is an identical feature of both the large number research and experience. Very often science has fought against old principles based on experience and later, when the progress in scientific research has proved the essential point of that rule to be true, science has been forced to acknowledge the truth of those rules (weather forecast rules, the healing power of certain herbs and substances, miracles and suggestion).

He who is constantly working with the law of large numbers will here again find, that finally experience and not theory is right. The only fault men commit is, that they apply experience mostly too sensibly and, betrayed by imaginations although right in themselves, generalize too much. With the large number research experience is working together with the exactitude of mathematical principles; it does not at all rank below pure scientific methods concerning reliability and besides that it has the great advantage of direct applicability on practice which is mostly not a striking feature with experiments made on a laboratory scale. No doubt the large number research will therefore prove more and more a valuable aid in industrial research.

It may be added that I have published a proposal of applying that method in industrial research first in April 1922.[1]

A detailed summary is published in the report No. 43 of the 16th of April 1924 of the Sub-Committee on Materials of the Verein deutscher Eisenhüttenleute; an American publication is to be found in "Testing", Vol. 1 (1924) No. 3: "The Utilization of Statistics".

Discussion—Some Factors Affecting Coercive Force and Residual Induction of Some Magnet Steels.

(Continued from Page 194)

quenching to restore spoiled magnet steel, we may state that the effects obtained vary to some extent with the composition. The lower chromium steels seem to respond more readily than the higher ones and may be restored to or nearly their as rolled values. It is our experience that the maximum effect is attained at 1800 degrees Fahr. or slightly above. We have not found any advantage in air quenching from temperatures above this up to 2200 degrees Fahr. We have not been able to restore the higher chromium steels to their as rolled values by air quenching up to 2200 degrees Fahr.

Our experience with tungsten steels is confined to Table XVI. However, the use of air quenching from a temperature of 1800 degrees Fahr., or slightly above, to partially restore spoiled magnet steel is a risky procedure from the operating point of view in the commercial production of magnet steels.

[1]Reports of the Committees of the Verein deutscher Eisenhüttenleute, report of the Sub-Committee on Materials No. 18, April 18, 1922.

THE CARBON CONTENT OF PEARLITE IN IRON-CARBON ALLOYS CONTAINING ONE PER CENT SILICON

By Anson Hayes and H. U. Wakefield

Abstract

The authors review a modification of the diagram for pure iron-carbon alloys, which was constructed to conform to experimental data for malleable white iron composition. The carbon concentration of point C had not previously been determined. The authors have obtained a value for the carbon content of this point and the principal object of this paper is to report the findings of the investigation.

As a result of an investigation of the graphitizing properties of iron-carbon alloys of white iron composition, with which one of the authors has been engaged for the past four years, a modification of the diagram for pure iron-carbon alloys was recently published.[1,2]

This modified diagram is shown in Fig. 1. It was constructed to conform to such experimental data as was available at that time. For convenience the sources of the experimental work will be repeated here. For the temperatures of points J and C, the extrapolation values of Hayes, Flanders and Moore[3] were used. They are 771 degrees Cent. and 759 degrees Cent. respectively. The equilibrium carbon concentration at point J was taken from Schwartz[4] as 0.57 per cent.

The carbon concentration of point C had not been determined at the time Bulletin 71 of the Engineering Experiment Station was issued.

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[1]Anson Hayes, W. J. Diederichs, and H. E. Flanders, Bulletin 71, Engineering Experiment Station, Iowa State College (1924).

[2]Also, Preprint No. 427, American Foundrymen's Association, October 11, 1924.

[3]Transactions, American Society for Steel Treating, Vol. 5, p. 183 (1924).

[4]Schwartz, Payne, Gorton and Austin, Conditions of Stable Equilibrium in Iron Carbon Alloys, *Transactions*, American Institute of Mining and Metallurgical Engineers, 68, 916.

A paper presented before the Cleveland Convention of the Society, September, 1925. Dr. Anson Hayes is professor of physical chemistry and metallography, Iowa State College, Ames, Iowa. H. U. Wakefield is associated with Dr. Hayes.

What is believed to be a good value for the carbon content of this point has since been obtained and the principal object of this paper is to report the findings in this investigation.

The intersection of the A_3 line with the temperature axis was taken at 900 degrees Cent. This is in accordance with the observations of Gonterman,[5] in which he states, "In Osmonds

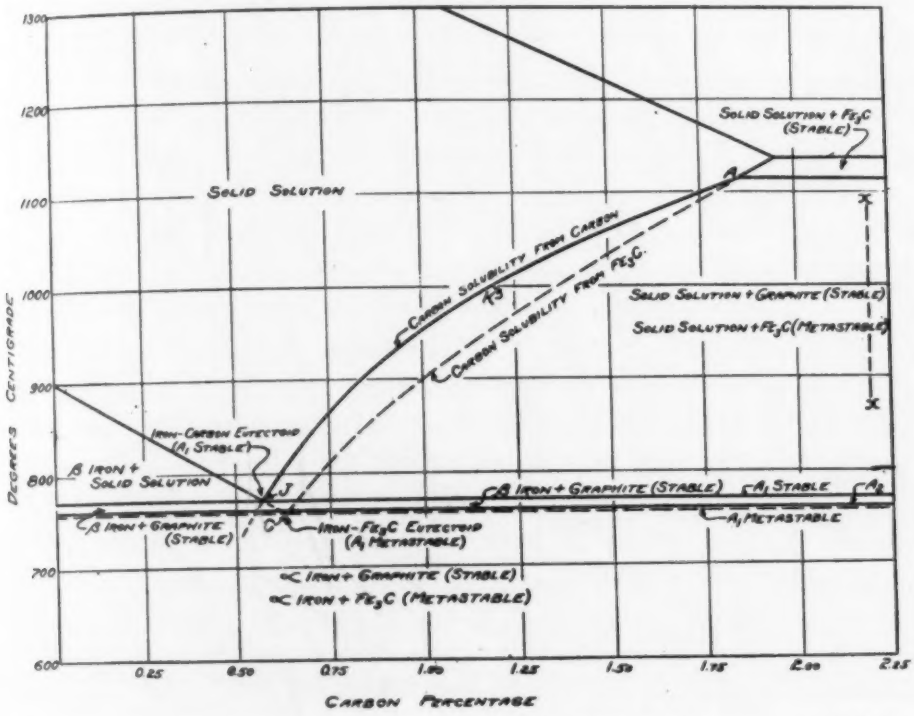

Fig. 1—Constitutional Diagram for Iron-Carbon Alloys of White Cast Iron Composition.

(iron-silicon) alloys the temperature of transformation from gamma to beta iron was almost independent of the silicon percentage."

With those presented by Yensen,[6] in which the iron-silicon diagram shows only a slight rise in the gamma to beta transformation even up to 8 per cent silicon and also with the statement of Charpy and Cornu-Thenard,[7] "The authors are able to confirm as different observers have pointed out that the A_3 point rapidly decreases (in intensity) when the percentage of silicon rises, at the same time rising slightly on the temperature scale."

[5]Gonterman, *Journal*, Iron and Steel Institute, No. 1, p. 432 (1911).

[6]Engineering Experiment Station, Bulletin No. 83, University of Illinois, p. 16.

[7]*Journal*, Iron and Steel Institute, No. 1, p. 301 (1915).

The A_3 line was then drawn through the point whose coordinates are 0.57 per cent carbon and 771 degrees Cent. It was then extended through J until the temperature corresponding to 759 degrees Cent. was reached. This value was that obtained by Hayes, Flanders and Moore.[8]

This method gives a value of 0.64 per cent for the carbon content of point C, i. e., of pearlite. This projection of the straight line to point C was made possible by the work of Scott,[9] which places the A_2 line at 761 degrees Cent. in an iron carbon alloy containing 1 per cent silicon. This is only 2 degrees Centigrade above A_1 metastable, as stated above.

The rather interesting fact that point J (the iron-carbon eutectoid) falls nearly on the A_3 line of the pure iron-carbon diagram was noticed at the time the work published under reference (3) was completed. The method just given for locating point C, of course, places it on this same A_3 line.

The value for the carbon content of pearlite in a one per cent silicon alloy obtained in the present investigation, when used with the temperature value 759 degrees Cent. for a 1 per cent silicon alloy, proves to be in satisfactory agreement with this manner of drawing the A_3 line. That is, both points J and C (A_1 stable and A_1 metastable) occur very nearly upon the same A_3 line.

Note: (While it was possible to predict that points J and C would be very nearly on the same straight line, A_2 being so near A_1 metastable, it is considered rather an accident that the A_2 line for the pure iron-carbon system and that for a 1 per cent silicon alloy would have the same slope and thus coincide.)

This may be considered strong evidence that the solid solution formed from carbon and that from iron-carbide are the same. They probably differ only in the concentration of dissolved carbon which represents austenite saturated with carbon from carbon in one case, and carbon from the metastable body iron-carbide in the other. It may be possible that all of the dissolved carbon is not in the same form. There may be various forms of the dissolved substance in solution, as is the case in liquid solution. If such is the case, an equilibrium between the various forms probably exists. Whether one form exists or whether two or more forms of dissolved carbon are in equilibrium, it is to be ex-

[8] *Ibid.*

[9] *Chemical and Metallurgical Engineering*, 28, 212 (1923).

pected that beta iron will separate where the carbon solubility line from carbon intersects the A_3 line for a 1 per cent silicon alloy. Furthermore, alpha iron should separate from the solid solution where the Acm line intersects the $A_{2.3}$ line. Since the A_2 line is so near the temperature of A_1, this places both A_1 stable

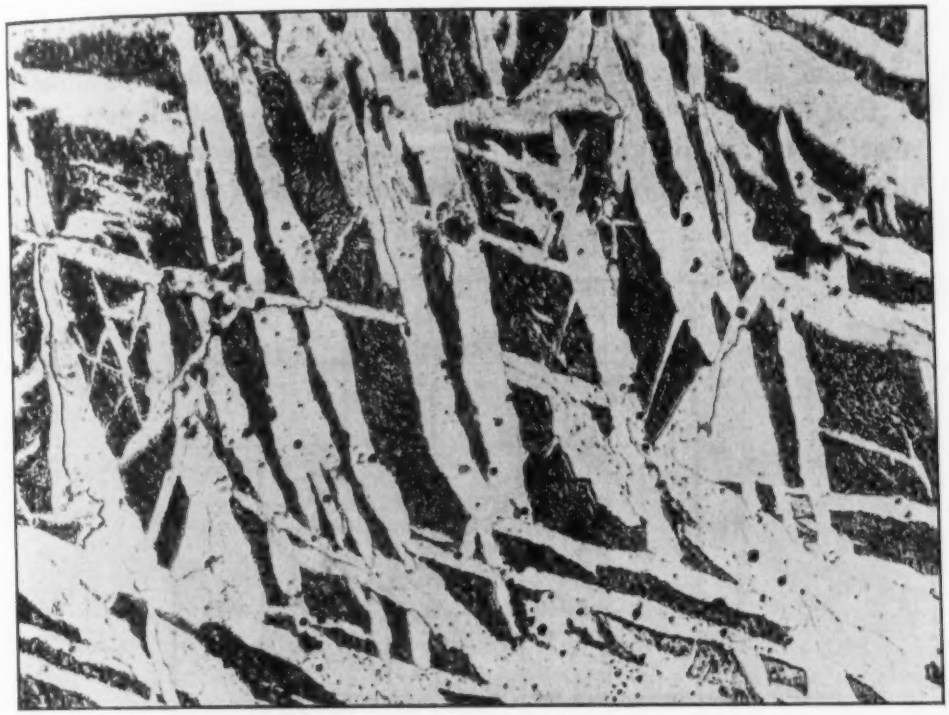

Fig. 2—Typical Structure of Alloy Investigated. Magnification 150X.

and A_1 metastable on essentially the same straight line drawn from 900 degrees Cent. and zero carbon concentration.

There probably is considerable doubt as to whether the point A of Fig. 1 should be above or below the solidification temperature for austenite in equilibrium with cementite. In any case its exact location is not known. It was placed below the solidification temperature of these two bodies in conformity with the conclusions of Honda,[10] that iron-carbide is stable immediately below its solidification temperature.

The line AJ was obtained by drawing a smooth curve through the lowest solubility values given by Schwartz. The line AC was

[10] *Science Report*, Tohoku Imperial University, 1st Series, No. 11, p. 119 (1922).

drawn to connect A and C and to fall to the right of all values obtained by Schwartz. Its experimental determination from solubility studies would offer grave experimental difficulties.

Method of Determining Carbon Content of Pearlite as a Function of the Silicon Content

The chief assumption made as a basis for the determination is that the fraction of the area of the cross-section covered by pearlite in an alloy of any particular silicon content is proportional to the combined carbon content.

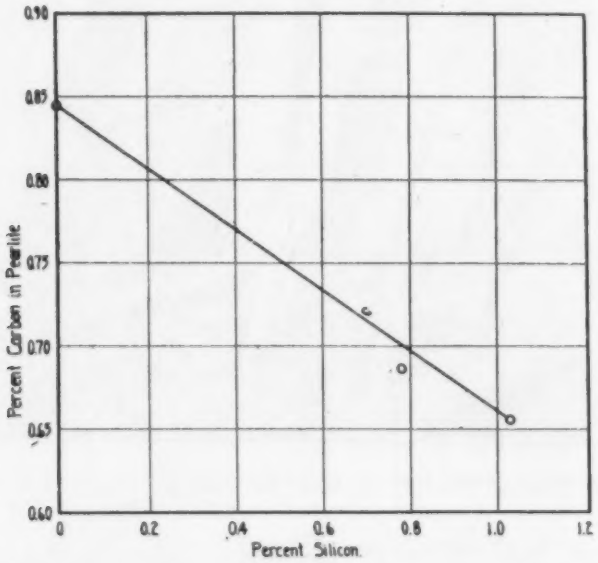

Fig. 3—Carbon content of Pearlite for varying amounts of Carbon and Silicon.

Alloys of varying silicon content and containing combined carbon of such a value as to produce sufficient pearlite to cover from 30 to 60 per cent of the cross-sectional area were made up. The areas of ferrite and pearlite were then carefully measured. The samples were then milled up and determinations for carbon and silicon were made.

The carbon content of pearlite was then calculated by dividing the combined carbon content by the fraction of the area covered by pearlite. The per cent of carbon in pearlite thus obtained was then plotted against the silicon content. By draw-

ing a smooth curve through the points so obtained, values of the carbon content of pearlite for any silicon content within the range of this investigation may be interpolated. This is shown in Fig. 3.

Table I

Data for Relative Areas of Pearlite and Ferrite for Alloy No. 1

Section No.	Area as Counted: Pearlite	Ferrite	Spots	Total
I	53.5	45.0	2.0	
	43.5	53.0	0.5	
	37.0	62.5	1.0	
	38.0	62.5	1.5	
	50.5	47.0	2.0	
MEAN	44.50	54.0	1.4	99.9
II	49.0	54.0	0.5	
	52.5	47.0	1.0	
	41.5	58.5	0.0	
	34.0	64.5	1.5	
	43.0	57.0	1.0	
MEAN	44.0	56.2	0.8	101.0
III	37.5	66.5	0.0	
	48.0	47.0	1.0	
	43.0	54.0	0.5	
	49.5	51.0	1.5	
	45.0	54.5	0.0	
MEAN	44.6	54.6	0.6	99.8
IV	66.0	33.5	0.0	
	41.0	58.0	2.0	
	49.5	49.0	0.0	
	45.0	52.0	0.0	
	38.5	59.0	3.5	
MEAN	48.0	50.3	1.1	99.4
MEAN OF ALL VALUES	45.30	53.77	.98	100.02

Considering only pearlite and ferrite, part of area covered by each:

Pearlite 45.67%

Ferrite 54.33%

The alloys were made by melting in a magnesite crucible armco iron to which had been added the necessary quantities of pure graphite and ferrosilicon. They were allowed to cool in the furnace at such a rate that well defined pearlite was formed. An

effort was made to use the same rates of cooling for the various alloys since it was thought that the carbon content of pearlite might vary somewhat with the rates of cooling. Slugs weighing about one hundred grams were made.

Table II

Data for Relative Areas of Pearlite and Ferrite for Alloy No. 3

Section No.	Area as Counted: Pearlite	Ferrite	Spots	Total
I	42.0	60.0	4.5	
	42.0	60.0	1.5	
	40.5	60.0	2.5	
	35.5	61.0	5.0	
	51.5	50.0	1.0	
MEAN	42.3	58.2	2.9	103.4
II	33.5	65.5	3.0	
	41.5	56.5	3.5	
	40.5	50.0	9.0	
	43.5	55.5	3.0	
	45.0	55.0	0.0	
MEAN	40.8	56.5	3.7	101.0
III	42.0	58.5	2.0	
	38.5	57.5	3.5	
	41.5	58.5	0.5	
	45.0	55.5	0.5	
	42.0	56.5	2.5	
MEAN	41.8	57.3	1.8	100.9
IV	40.5	60.5	1.0	
	44.5	51.0	2.5	
	42.0	52.5	3.5	
	43.5	51.0	3.5	
	36.5	62.5	2.5	
MEAN	41.4	55.5	2.6	99.5
MEAN OF ALL VALUES	41.56	56.88	2.75	101.19

Considering only pearlite and ferrite, part of area covered by each:

Pearlite 42.22%
Ferrite 57.78%

These were sawed apart at four places and four of the exposed faces were measured. The areas of pearlite, ferrite,

and spots were measured on five fields chosen at random on any face, and the mean value was obtained.

If the sample showed lack of uniformity in its structure, another was prepared. Tables I and II give typical data resulting from such measurements. In Table III is shown the results for the four alloys investigated. Fig. 2 shows a typical structure at the magnification used. The data of Table III is plotted in Fig. 3.

Table III

Data for the Alloys Used to Determine the Carbon Content of Pearlite for Varying Amounts of Carbon and Silicon

No. of Alloy	Pearlite	Ferrite	Combined Carbon	Graphitic Carbon	Silicon	Carbon Content of Pearlite
1	45.67%	54.33%	0.3895%	No evidence of any	None	0.853%
2	65.29%	34.71%	0.4709%	Trace	0.710%	0.7213%
3	42.22%	57.78%	0.289%	Less than 0.004%	0.789%	0.6845%
4	70.68%	29.32%	0.468%	0.013%	1.113%	0.6621%

Interpolation on this graph gives 0.669 per cent for the carbon content of pearlite for an alloy containing 1 per cent silicon.

The agreement is well within the experimental error for the location of point C on the diagram of Fig. 1.

Discussion

R. S. ARCHER:—This diagram is based on the assumption that the iron-carbon system may be regarded as existing in two forms, the stable, or the iron-graphite system, and the metastable, or iron-cementite system. This is the common assumption and is also the assumption upon which is based the A. S. S. T. data sheet on the iron-carbon diagram.

We should not overlook, however, that it is still an assumption. As Schwartz pointed out in his paper the other day, pure iron-carbon alloys are difficult to graphitize and perhaps will not graphitize at all, and it may be that in systems involving graphite we are dealing with more than iron and carbon,—it may be that silicon or some other element is an essential part of that system, and therefore, that the fundamental assumptions involved in this discussion may need some change. But for the present, until something positive is demonstrated along that line, I think we can proceed on this basis and regard

the system as existing in the two forms, the stable and the metastable.

The present authors have assumed that the A_3 point of an iron-silicon alloy containing one per cent silicon is unchanged, that it occurs at the same temperature as the A_3 point in pure iron, at about 900 degrees Cent. They quote a number of references in support of this assumption. I think there is considerable evidence of a quite positive nature to the effect that silicon definitely raises the A_3 point in pure iron. I think perhaps Mr. Ruder has as good evidence on the subject as any. I think he has traced the A_3 point in iron-silicon alloys of very low carbon content until it disappears, and I think it only takes a few per cent of silicon to push A_3 clear up into the delta iron range. I do not know just what the increase would be for one per cent silicon, but I think it would be substantial,—enough to take account of in the diagram.

Secondly, I was interested to note that the present author has retained the designation "beta iron" in drawing his diagram. Now, of course, whether we call iron in this temperature range beta iron or alpha iron is a matter of choice; it depends on what we wish to consider an allotropic change. I have considered that even though there are definite discontinuities in iron at the A_2 temperature, and that even though these discontinuities may seem sufficient to some people to justify calling iron above A_2 beta iron and below A_2, alpha iron, nevertheless, whatever these changes are, they are not changes in phase, they are changes taking place within a body-centered crystal of the substance we know as alpha iron, and the constitution diagram represents phase changes only, I omitted the A_2 line from the diagram, and do not see the justification for referring to this constituent as beta iron in the present case. I would like to hear the author's comments and reasons on that point.

Another point concerns experimental procedure in determination of the carbon content of the eutectoid in these steels. The author has made small melts of iron-silicon-carbon alloys, allowed these melts to cool in a crucible, presumably at rates which were nearly the same in all cases, and which were fairly slow. He has then taken the carbon content of the eutectoid from the apparent areas of pearlite and ferrite. It has been pointed out before—I will refer especially to Dr. Krivobok's work as given in his paper at the last annual convention—that the apparent carbon concentration of the eutectoid differs markedly according to the rate of cooling. I think Dr. Krivobok found that steel containing as low as five-tenths per cent carbon, straight carbon steel, could be obtained in the pearlitic condition with little or no free ferrite, simply by increasing the cooling rate. And while the work reported in this paper may be entirely accurate and reliable, it would seem to be suggested that different rates of cooling be adopted and the results extrapolated to zero rate in order to eliminate this rate effect.

Written Discussion:—By H. A. Schwartz, National Malleable and Steel Castings Co., Cleveland

The present paper is most welcome as a source of information upon a subject but imperfectly developed in the literature. The writer has had occasion to study the subject for somewhat the same purpose as the authors, and it may be of interest to record here some observations calculated to extend the field a little further.

Fig. 3 of the authors' paper leads to the conclusion that within the limits of composition considered, silicon replaces about one-fifth of its own weight of carbon in pearlite. This relation is not, however, applicable with an indefinite increase in silicon content. Thus, Honda and Murakami[1] show that at 2.14 per cent silicon, an alloy containing 0.46 per cent carbon is strongly hypoeutectoid, and at 2.26 per cent silicon, one containing 0.78 per cent carbon is strongly hypereutectoid. The writer estimated from their micrographs, that the pearlite carbon would be of the order of magnitude of 0.65 per cent, while an extrapolation from Hayes' and Wakefield's data would point to about 0.40 per cent carbon.

A specimen of steel prepared in this laboratory by Meacham,[2] containing 0.59 per cent carbon and 4.30 per cent silicon was very slightly hypereutectoid.

These facts in no wise invalidate the conclusions of the authors, but point to the fact that the curve correlating silicon and carbon in pearlite, has a discontinuity of direction, presumably at the silicon concentration at which A_1 and A_2 coincide.

The writer made the assumptions:—

1. That the presence of silicon would not alter the effect of a unit of carbon on A_2 or $A_{2\text{-}3}$;
2. That at 4.00 per cent silicon, the eutectoid carbon content is 0.60 per cent;
3. That silicon free pearlite contained 0.92 per cent carbon;
4. That A_1 may be calculated as being (707 + 28 ¼ × Si%) degrees Cent., which represents the mean of collected data by six independent observers, and well over 150 individual determinations;
5. That A_2 is represented by (790 — 15 × Si%) degrees Cent.[3]

From these assumptions, the location of the metastable eutectoid in temperature, and carbon and silicon concentration was determined, as the intersection with the A_1 plane of either the A_3 or $A_{2\text{-}3}$ planes, depending upon whether A_1 fell above or below A_2.

The methods were those usual in descriptive geometry, and the result is shown in Fig. 1, in which the Hayes data are shown for comparison. It will be noted that while the determinations fall uniformly below the reasoning, the agreement is, perhaps, as close as was to be expected.

Quite eminent authorities have in the past been unable to agree as to the precise location of the eutectoid in the binary alloy in the range between 0.85 per cent carbon and 0.92 per cent carbon, a decision being probably beyond the range of precision of the available experimental methods. Thus, for instance, it is not positively proven that the carbon content of pearlite

[1] "On the Structural Constitution of Iron-Carbon-Silicon Alloys," *Science Reports* of Tohoku Imperial University, Sendai, Japan, Vol. XII, No. 3.

[2] "Effect of Silicon on the Thermal Critical Points of Steel," TRANSACTIONS of the American Society for Steel Treating, Vol. 4, 1923, p. 635.

[3] Murakami and Honda, loc. cit. and "On the Equilibrium Diagram of Iron-Silicon System," Takejiro Murakami, *Science Reports* of Tohoku Imperial University, Sendai, Japan, Vol. X, No. 2.

in quite low carbon material is not lower than in higher carbon hypoeutectoid steels, nor that ferrite is absolutely carbon free.

In Fig. 2 is shown a photomicrograph of a malleable casting, so cooled

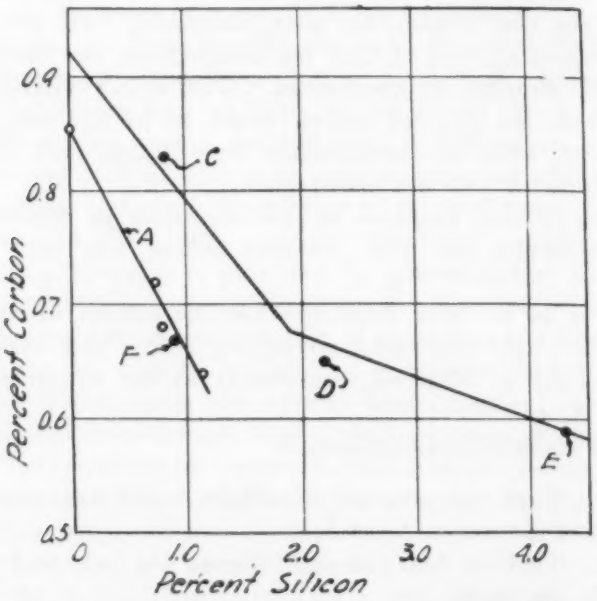

Fig. 1—A-Line and Points, After Hayes and Wakefield. B-Line Estimated by Schwartz. C from Slightly Hypereutectoid Malleable Iron Specimen of Pearlitic Matrix, D Estimated After Honda and Murakami, E Meacham's Steel Slightly Hypereutectoid. F from Somewhat Hypereutectoid Malleable Iron Specimen.

as to be almost exactly of eutectoid matrix, though a little ferrite is present, as well as traces of proeutectoid cementite. It contains:

	Per Cent
Manganese	0.26
Silicon	0.82
Sulphur	0.040
Phosphorus	0.144±
Total Carbon	2.25
Graphitic Carbon	1.41
Combined Carbon (by color)	0.82

which points to a carbon concentration in the eutectoid under 0.83 per cent in the presence of 0.82 per cent silicon. This point, also, is entered in Fig. 1.

In Fig. 3 is shown a photomicrograph of a somewhat similar underannealed malleable iron, containing

	Per Cent
Manganese	0.32
Silicon	0.89
Sulphur	0.033
Phosphorus	0.149
Combined Carbon	0.67

in which considerable areas of ferrite are found, and no cementite exists, the alloy being, therefore, distinctly hypoeutectoid. This point will be found located in Fig. 1, very near Hayes' and Wakefield's points.

It follows from the preceding, that above say 2.00 per cent silicon, possibly less, silicon does not reduce the carbon content of pearlite appreciably. Now, A_1 can rise with increasing silicon from two causes, the decrease of carbon in the eutectoid which it produces, and the increase in A_3 which it produces, per se. If now, A_1 increases with increasing silicon up to say 4 or 5 per cent, as shown by Meacham, loc. cit., and many others, and if the carbon content of the eutectoid does not change above 2.00 per cent, then as silicon rises from 2.00 to 4.00 per cent, A_3 must rise by the same amount as A_1.

The assumption of Hayes and Wakefield, that silicon has but little effect on A_3 is not shared by the writer for the following reasons:

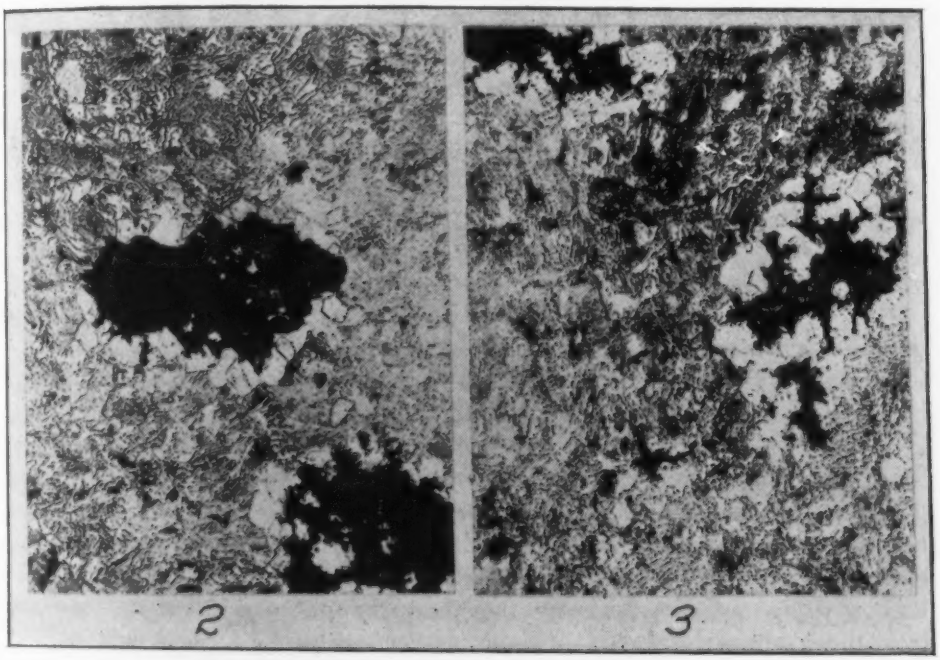

Fig. 2—Underannealed Malleable Iron Having 0.83 Per Cent Combined Carbon. Pearlite, Ferrite and Cementite Matrix. Etched in Dilute Nitric Acid. 100X. Fig. 3—Underannealed Malleable Iron Having 0.67 Per Cent Combined Carbon. Ferrite and Pearlite Matrix. Etched in Dilute Nitric Acid. 100X.

Of the references quoted by the authors, Gontermann did not concern himself in detail with A_3; Yensen[4] merely quotes Gontermann without corroboration; and while Charpy and Cornu-Thenard are correctly quoted, their actual observations showed a rise of 35 to 50 degrees Cent. in A_3 for 1.00 per cent increase in silicon, up to the limit where they could no longer follow it.

Personal communications to the writer, one from an observer of out-

[4] "Magnetic and Other Properties of Iron-Silicon Alloys Melted in Vacuo," Trygve D. Yensen, University of Illinois, Bulletin No. 83, Engineering Experiment Station.

standing reputation, have stated that 1.00 per cent of silicon raises the A_3 about 100 degrees Cent. Furthermore, the Gontermann-Yensen diagram, to which the authors refer, is now known to be wrong in principle. The A_3 line ascending, merges with the A_4 line descending, instead of running out toward a eutectoid solidus or a line parallel thereto. This suggestion, perhaps, first publicly made by Oberhoffer, and enlarged upon by Wever,[5] requires a rise in A_3 of about 135 degrees Cent. per 1.00 per cent silicon.

The problem of the effect of silicon on the alpha (beta) gamma transformation is inherently ill suited to thermal investigation, and will probably be solved only by the methods of radio spectrometry, or, perhaps, by magnetic analysis or determinations of thermal electromotive force. So far as the writer is aware, no experimenter who was able to observe A_3 in the presence of silicon at all, has failed to find it above 900 degrees Cent., i. e.,

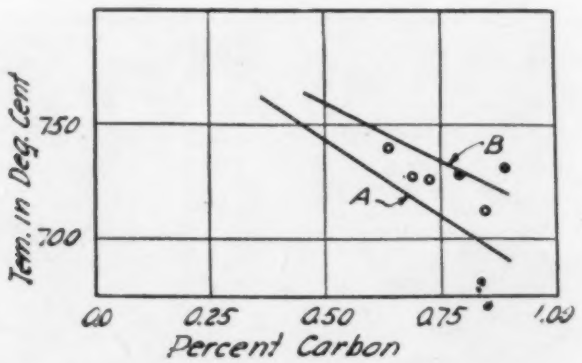

Fig. 4—A-Line is A_{2-3} Line, After Carpenter and Kealing. B-Line is A_{2-3} Line, After Howe and Levy. Open Circles, After Hayes and Wakefield Calculating A_1 by Formula of Schwartz. Solid Circles Schwartz Data.

failed to note a rise in A_3 with increasing silicon content. As to the magnitude of this increase, we are, as yet, unable to form a conclusion. The authors disregard the difference in direction between A_3 and A_{2-3}, which may possibly be a reason why they find the postulate, that A_3 in binary iron-silicon alloys is nearly constant, as concordant with their data.

In Fig. 4 the writer has drawn the A_{2-3} lines of the binary iron-carbon system according to Carpenter and Kealing,[6] and Howe and Levy.[7] Assuming the equation $A_1 = (707 + 28\ ¼\ Si)$ degrees Cent., the 4 points of Hayes and Wakefield have been inserted for comparison. The Carpenter and Kealing data are from cooling curves, and hence, are theoretically not too high. Unfortunately, the writer has been unable to inform himself as to whether this is true also of Howe and Levy. In any event, the results of the present authors are at least approximately in accord with the assump-

[5] "Zur Allotropie des Eisens," Wever, *Stahl und Eisen*, July 9, 1925, p. 1208.

[6] "The Range of Solidification and Critical Ranges of Iron-Carbon Alloys," *Journal* of the Iron and Steel Institute, 1901. I. 224 (British).

[7] Fig. 23 and accompanying references, "Metallography of Steel and Cast Iron," H. M. Howe.

tion that A_{2-3} is not much affected by silicon content, and furnish no evidence regarding the locus of A_3.

The constancy of A_{2-3} tempt one into the speculation whether this is an expression of the resultant of the opposite effects of silicon on A_2 and A_3, respectively. Having in mind the fact that the carbon content of silicon free pearlite, as obtained by Hayes and Wakefield, corroborates the lowest accepted value, it seems likely that the true values in the presence of silicon will be very nearly as reported by them, but possibly a little higher.

The authors' data show that in the metastable eutectoid, two atoms of silicon replace one of carbon, very nearly. The writer and co-workers[8] have shown that the ternary stable eutectoid ceases to exist at above 3.75 per cent silicon, which corresponds to a very similar quantitative effect of silicon in the two cases. In the same publication, it was shown that in the pseudo martensitic areas, which finally become pearlite, the carbon concentration approached a value somewhat above 0.60 per cent in the presence of 1.00 per cent silicon, thus confirming the authors to some extent.

Wark[9] showed that the binary stable euctectoid contained 0.86 per cent carbon, closely confirming the authors, and Ruer and Iljin[10] showed the stable binary eutectoid to contain 0.72 per cent carbon. There is here a difference of 0.14 per cent, while the authors' value of 0.669 per cent at 1.00 per cent silicon compared with the writer's 0.57 per cent in the stable eutectoid shows a difference of only 0.07. If the effect of silicon is nearly the same in both systems, then there is indicated either a high value for Wark, or the writer, or a low value for the authors at 1.00 per cent silicon, or for Ruer and Iljin, in the absence of silicon. It is most unlikely that the difference should decrease with increasing silicon.

The fact that according to the present writer's reasoning, the lines begin to diverge where A_2 passes below A_1, due to the fact that the metastable eutectoid then becomes of nearly constant carbon, while the stable eutectoid decreases in that element regularly, may form an explanation of the fact that above about 2.00 per cent silicon, the formation of graphite is much facilitated. The writer further believes that in view of the small differences involved, the authors' determinations cannot be regarded as yet establishing the identity of the A_{2-3} lines of the two systems, but only that these two lines are close together and nearly parallel.

The purpose of the present discussion is to corroborate, from outside considerations, the authors' findings as to the carbon content of pearlite in the presence of silicon without subscribing to their conclusions regarding the locus of A_3 at lower carbon or higher silicon concentrations. Incidentally, it is hoped that this discussion may obviate errors of application of the authors' data to high silicon alloys by extrapolation, for which they would, in no wise, be responsible.

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[8] "Effect of Silicon on Equilibrium Diagram of System Carbon-iron Near Eutectoid Points," H. A. Schwartz, H. R. Payne, and A. F. Gorton, American Institute of Mining and Metallurgical Engineers, Vol. LXIX, p. 791.

[9] "Bestimmung der Löslichkeitsinie des Eisencarbids (Fe_3C) in Gamma Eisen," *Metallurgie*, 1911, No. 22, p. 704.

[10] "Zur Kenntnis des stabilen Systems Eisen-Kohlenstoff," *Metallurgie*, 1911, No. 4, p. 97.

Authors' Written Reply to Discussion of Paper. By Dr. Anson Hayes

I wish to submit the following written reply to oral and written discussions.

In my oral reply on the convention floor, I raised the question "Is a change of crystal lattice necessary to the formation of a new phase as the term *phase* is implied by the phase rule?"

I think beyond question it is not, for if the A_2 change should take place sharply at a fixed temperature, the requirements of the phase rule that the system of one component in the presence of two solid phases and at a fixed pressure of one atmosphere be nonvariant, would have been satisfied.

It is a fact that the A_2 change is spread over a considerable temperature interval, however it has not yet been proven that this spreading is not an extreme case of the lag which we find in nearly all transitions.

Because of the great difference in the magnetic properties of the iron below and above the A_2 point, it proves to be very convenient to retain the name beta iron even though the characteristics of this change may not fit the more or less arbitrary definitions of allotropy or of "phase" set up by various authorities in the field.

The authors of the paper under discussion desired most of all to select the data and nomenclature for Fig. 1 in such a manner as to avoid discussions of questions upon which authorities cannot reach a satisfactory agreement, and which are entirely aside from the purpose which our Fig. 1 was intended to serve.

The extrapolation to zero rates of cooling for the composition of pearlite in the series of alloys used in obtaining the data for this paper becomes practically impossible on account of graphitization taking place at lower rates of cooling. It becomes extremely difficult to determine graphitic carbon in an alloy containing total carbon of three-tenths per cent with sufficient accuracy to prevent the errors in this determination causing great irregularities in the individual determinations of the carbon content of pearlite.

In consideration of this difficulty, the procedure was adopted of cooling the alloy at such a rate as to give a value of carbon for pearlite that is generally accepted as being a good one.

The silicon alloys were then all cooled at as nearly this same rate as possible.

The rate used was also such as gave well-defined pearlite with no indication of divorcing of the ferrite and cementite lamellae.

Since spheroidizing takes place at lower rates of cooling it is questionable whether such an extrapolation would give significant results even if the analytical difficulty mentioned above did not exist.

In regard to the effect of silicon upon the temperature of the A_3 transition which has been raised by both Mr. Archer and Mr. Schwartz:

In a letter from Mr. W. E. Ruder of the General Electric Company at Schenectady, he informs me that their work has not been published but showed that the A_3 point disappeared at about 2% silicon.

In regard to the references which the authors quoted as authority for locating A_3 at 900 degrees Cent. in one per cent silicon alloys, I wish to say that these are the conclusions drawn by Gonterman, Yensen and Charpy in

summerizing their work, and peculiarly enough are the same authorities quoted by Mr. Schwartz[1] to prove that the A_3 is raised by the addition of silicon.

Mr. Schwartz calls attention to the fact that in the work of Charpy and Carnu-Thenard, their results show an actual rise of 35 to 50 degrees Cent. in A_3 for one per cent silicon. This appears to be true in their thermal analysis results shown in figures 1, 3, and 4, but is not corroborated by their dilatometer measurements shown in figure (2). The temperature reading at 0.26 per cent silicon is slightly higher than that at 0.06 but the value for A_3 where silicon = 0.57 per cent is at the same temperature as was obtained for the 0.06 per cent silicon alloy. We feel that their conclusions were justified from the results which they obtained. The work of Oberhoffer[2] and that of Wever, is worthy of consideration. Oberhoffer places the temperature of the A_3 transition in a one per cent silicon alloy at slightly less than 900 degrees Cent. while Wever places it at slightly above 950 degres Cent.

Since we have been unable to obtain a reference from which it is possible to determine to what extent, if any, the A_3 point is raised by one per cent silicon, it seems advisable to make no change at present. From this last reference there seems to be no doubt that at higher silicon contents A_3 is raised.

The authors wish to state that they drew the A_3 line from the point at which it cuts the temperature axis through the iron carbon eutectoid to the point where the so-called alpha-beta transition merges with the beta-gamma transition, and drew the A_{3-2} line from this point through the iron cementite eutectoid for one per cent silicon alloys, under the assumption that silicon does not affect the temperature of A_3.

Such a procedure is justified for the following reasons:

First, the fact that carbon may be taken into solid solution in austenite and precipitated from the solution as cementite and the reverse process that cementite may be taken into solution and the carbon may be precipitated indicates that there must be a mechanism for the conversion of carbon in each of these forms into the other. If we accept the concept of the solid solution as that which Wever presents and which reference Mr. Schwartz has quoted, we would conclude that the carbon in the austenite enters the interior of the face-centered cube whether it comes from carbon or from cementite and that the iron atoms in the cementite take their place in the regular positions of the iron in these face-centered cubes. If this is correct, the cementite is formed at the time the carbon is precipitated. At the iron carbon eutectoid carbon is precipitated without the formation of the carbide. This being the case, it follows that the difference between austenite saturated with carbon from carbon and that saturated with carbon from cementite is simply that a greater number of the face-centered cubes have their interior occupied by a carbon atom. Thus, there is no discontinuity in the nature of the solid solution austentite, over the whole concentration range of its existence.

One of the authors[3] has stated elsewhere that this same statement could

[1]Schwartz, Payne and Gorton, *Transactions*, American Institute of Mining and Metallurgical Engineers. Vol. 69, p. 792.

[2]*Stahl und Eisen*, Vol. 45, p. 1208, July, 1925.

[3]Hayes, Diederichs and Flanders, *Transactions*, American Foundrymen's Association, Vol. 32, I, p. 639, discussion.

be made of austenite in the presence of more than one form of the solute, if such forms are in equilibrium with each other.

In either of the above contingencies (beta) iron should separate where the carbon solubility line crosses the A_3 line and (alpha) iron should separate where the A_{cm} line crosses the A_{2-3} line. In case the situation is further simplified by assuming that the difference in beta and alpha iron is something similar to a rather abrupt increase in the specified heat of the latter, then the two lines A_3 and A_{2-3} should be drawn as a continuous curve with a rather abrupt change in the slope at the point where the A_2 and A_3 points merge.

For the pure iron-carbon system the well-known equation

$$-\frac{dT}{dx} = \frac{RT^2}{\triangle H}\left(\frac{1}{(1-x)}\right)$$

gives the relation between the slope of the A_3 line and the mole fraction x of carbon in the austenite in case carbon is soluble in gamma iron and insoluble in beta iron. Here T is the absolute temperature of the transition and $\triangle H$ is the heat absorbed when one gram mole of beta iron goes over into the gamma form. The application of the integrated form of this equation to the calculation of $\triangle H$ assuming A_3 for pure iron is 900 degrees Cent., A_2 is 768 degrees Cent. and that A_2 merges with A_3 at 0.40 per cent carbon gives a value of 5.9 calories per gram for the transition of beta to gamma over this interval. When this is compared with Meuthen's[4] value of 5.6 calories, the agreement indicates that at concentrations of less than $x=0.018$, the above equation may be applied with considerable precision.

It is plain from this equation that the heat absorption at A_2 requires that the slope of A_{2-3} line be numerically less than the slope of the A_3 line since at the point where A_2 merges with A_3 thermodynamics requires that heat absorbed at A_2 + heat absorbed at A_3 = heat absorbed at A_{2-3}.

The above relations hold for the pure iron-carbon system.

If a third component silicon, which is miscible up to one per cent be introduced, then the equation

$$\frac{dT}{dx} = (K-1)\frac{RT^2}{\triangle H}$$

gives the change in the temperature of the A_3 transition due to the presence of silicon. In this equation K is the distribution ratio of silicon between the beta and gamma iron and $\triangle H$ is the heat absorbed when one mole at solid solution (iron + silicon) is transferred from one phase to the other at constant composition. This equation shows that the temperature of the A_3 transition is independent of the silicon content in case $K=1$, that it is raised if K is greater than 1, and is lowered if K is less than 1. It should be stated that this equation is strictly true only in dilute solutions. It should be qualitatively true to much greater concentration. Now if K has a value near one and the presence of carbon up to 0.7 per cent does not influence the value of K

[4] *Ferrum*, Vol. 10, p. 1, 1912.

when one per cent silicon is present, equation (1) may be applied since the iron silicon solid solution may be considered the new solvent.

From the above considerations the following mechanism is considered to be best suited to represent the behavior of iron-carbon alloys containing one per cent silicon, on the assumption that one per cent silicon does not influence the temperature of A_3.

Along the A_3 line in iron-carbon alloys containing one per cent silicon, a solid phase separates in which carbon is practically insoluble. At 0.57 per cent (771 degrees Cent.) carbon (A_1 stable) the iron carbon eutectoid occurs. Beyond 0.57 per cent carbon in austentite, the solid solution at 771 degrees Cent. and below is metastable. However, since the constituent which must separate in order to transform these low carbon alloys over into the metastable condition is the same phase which separated from the solid solution for alloys containing less than 0.57 per cent carbon, the A_3 line should be extended through A_1 stable and to such a point as corresponds to the temperature (761 degrees Cent.) at which A_2 occurs. This manner of treatment is the result of applying the equation (1) over this range. Beyond the point where A_3 merges with A_2 the constituent which separates the authors designated as alpha iron and since $\triangle H$ is greater for the change alpha to gamma than for that beta to gamma, the A_{3-2} line should be drawn with a smaller numerical slope than the A_3 line. This is just as true whether beta iron is called an allotrope or not, since the heat content of beta is greater than that of alpha iron.

The authors consider that Fig. 1 is the simplest explanation of the behavior of white iron in the graphitizing range.

If K is far removed from the value of one, it can readily be shown that the silicon content of austenite when the carbon content of austenite is 0.57 per cent would be different for a 0.2 per cent carbon alloy and for one containing 0.5 per cent carbon. For the higher carbon contents used in white iron, i.e. 2.25 to 2.60 per cent carbon, this variation in behavior would not occur, since no alpha or beta iron forms in cooling such an alloy until A_1 stable is reached. The result of K being much greater than one would be to produce a large number of A_3 lines on the one per cent silicon plane, one for each different carbon content. In other words, it would be necessary to go to a three dimensional diagram to represent the exact behavior.

In order that the reader will not consider the lack of agreement between our data and the graph of Fig. 1 of Mr. Schwartz's discussion, as indicating the probable error of our data, the significance of assumption (1) of Mr. Schwartz should be kept in mind. This assumption is "that the presence of silicon would not alter the effect of a unit carbon on A_3 or A_{3-2}.

Our equation (1) of this reply

$$-\frac{dT}{dx} = \frac{RT^2}{\triangle H}\left(\frac{1}{1-x}\right)$$

shows that this assumption is equivalent to the statement that the transfer of a mole of solid solution of beta iron and silicon over to the gamma form would be accompanied by the same heat absorption as would occur when a mole of pure beta iron is converted into gamma form (providing of course, that the

temperature of the transition is not greatly affected by the presence of silicon). Strictly it would mean that $\frac{RT^2}{\triangle H}$ would be the same for the two cases.

There is at present no known method of predicting that such would be the case.

Thus the significance of the near agreement between our data and the graph of Mr. Schwartz's Fig. 1 is that his assumption (1) happened to be not far from a correct one.

SOME EFFECTS OF HYDROGEN ON IRON AND THEIR BEARING ON A REPORTED TRANSFORMATION AT 370 DEGREES CENT. (698 DEGREES FAHR.)

By Henry S. Rawdon, Peter Hidnert, and W. A. Tucker

Abstract

The purpose of the investigation was to find whether a recently reported "transformation" in iron at 698 degrees Fahr. (370 degrees Cent.) might not be an effect due to hydrogen. By thermal analysis an "irregularity", appearing as an evolution of heat upon heating, the maximum being around 572 degrees Fahr. (300 degrees Cent.) was detected in some iron specimens. This was more pronounced in specimens which had been heated in hydrogen. An irregularity in thermal expansion around 698 degrees Fahr. (370 degrees Cent.) was likewise detected in some similarly treated specimens. Iron containing an appreciable amount of iron oxide showed this phenomenon best. Iron charged with "cathodic" hydrogen behaved irregularly in thermal analysis on heating, but showed an absorption of heat. The results of the investigation did not confirm the existence of the reported transformation. A possible explanation of the results obtained based upon an X-ray diffraction study is suggested.

I. Introduction

THE immediate occasion for this investigation was to check the results recently reported by Sirovich[1] on a transformation in pure iron and low carbon steels at approximately 698 degrees Fahr. (370 degrees Cent.). By a series of dilatometric measurements of iron as it was being heated in a bath of fused tin, Sirovich obtained evidence of a rather abrupt change in the rate of expansion at 698 degrees Fahr. (370 degrees Cent.) upon

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[1]Sirovich, G., La transformazione polimorfica del ferro a 370° C. e la possibilita di soluzione della cementite nel ferro. Gaz. chim. Italiana, 53, 674-688, 1923.

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heating. He stated that the phenomenon was observed in electrolytic iron, Armco (open-hearth) iron and low carbon steel (0.07 per cent carbon) and attributed it to a "polymorphic change" of some kind in the ferrite. He concluded that ferrite exists in two forms, which he designated as a_1, and a_2. No curves to show the behavior of the material on cooling were given and the question of the reversibility of the change was not discussed. The curve in Fig. 1 is that given by Sirovich for electrolytic iron. The one for open-hearth iron was essentially the same as this one.

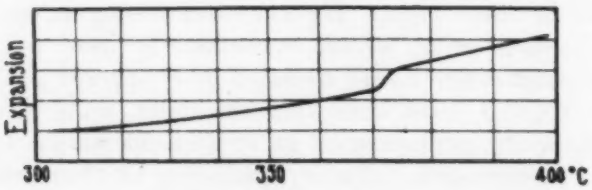

Fig. 1—Dilatation Curve of Electrolytic Iron (Sirovich). The Specimen was Suspended in a Bath of Molten Tin and the Change in the Buoyant Force Noted as the Bath was Heated.

In the low carbon steel, the transformation did not appear to be so pronounced. A Montemartini-Losana dilatometer was used for measuring the expansion, the specimen whose dilatation was being measured being suspended in a bath of fused tin. The true expansion of the iron, therefore, is not shown by the curve but only the change which occurred around 698 degrees Fahr. (370 degrees Cent.).

The existence of a "transformation" in iron reported by Sirovich as occurring below the well established "critical points", is a matter of very considerable importance. No sure indications of such transformation had been obtained in any of the many thermal analyses of pure iron which have been made at this Bureau during the past fifteen years. It appeared, however, that this phenomenon might have some bearing on a study which was being made of certain microstructural features of ferrite, hence one reason for examining it. In the study of the microstructure of ferrite, the possible influence of hydrogen had already been considered. The results obtained suggested that, perhaps, some effect of hydrogen on iron might account for the "transformation" reported by Sirovich. Previous observations at this Bureau, on the effects produced on steel by the furnace atmosphere during annealing (Table 1, note a) also helped to strengthen the sug-

gestion that the reported "transformation" might be only apparent and not a real one.

In the experimental method as reported by Sirovich, hydrogen does not play a part. Details concerning the preparation of the specimens were not given, however. The use of a furnace atmosphere of hydrogen, or at least one rich in hydrogen, is not at all uncommon in the preparation of samples of such materials as were used, and the specimens may have been subjected unintentionally to a treatment similar to that used intentionally in the present investigation, as described below. Mention may also be made of the alloying action of the molten tin upon the surface of the iron specimen suspended in it, which occurs to an appreciable extent. Sirovich does not appear to have considered this in drawing the conclusion which he did. In the present investigation, this possible source of error has not been studied.

While the present investigation relates primarily to the influence of hydrogen treatment on iron as shown by thermal analysis and expansivity measurements on the hydrogen-treated iron, it also attempts to discover the existence of the reported 698 degrees Fahr. (370 degrees Cent.) transformation in an entirely different manner from that used by Sirovich.

II. Previous Work on Hydrogen in Iron

Two rather complete bibliographies on the general subject of gases in solid metals have been published.[2,3]

The following references relate to those phases of the subject which appear to have a bearing upon the reported transformation in iron at 698 degrees Fahr. (370 degrees Cent.).

St. Claire-Deville and Troost[4] showed as early as 1863 that hydrogen will diffuse readily through hot (solid) iron. Graham[5] concluded from his study of meteoric iron that, in addition to being permeable to hydrogen, iron, as well as certain other metals, retains appreciable amounts of the gas, after being heated in an

[2]Landolt-Börnstein, Physikalische-Chemische Tabellen, 5th edition (1923), pp. 781-784, Solubility of Gases in Solids.

[3]Alleman, G., and Darlington, C. J., Occluded Gases in Ferrous Alloys, *Journal*, Franklin Institute 185, pp. 161-198; 333-357; 461-479, (1918).

[4]St. Claire-Deville and Troost, The Diffusion of Hydrogen Through Iron, *Comptes Rendus*, 57, 965-967 (1863).

[5]Graham, Thomas, On the Occlusion of Hydrogen Gas by Meteoric Iron, *Proceedings*, Royal Society 15, 502-3 (1866-7). Also: On the Occlusion of Hydrogen Gas by Metals, *Proceedings*, Royal Society 16, 422-7 (1866-8). *Journal*, Chemical Society 20, 257-292 (1867).

atmosphere of hydrogen. In his later experiments, a number of metals including iron were treated with hydrogen by (1) heating to "redness" in vacuo to expel any gas initially present, (2) heating in hydrogen, (3) cooling in hydrogen and (4) heating a second time, as in (1), to determine the amount of gas which had been "occluded". He stated that no difficulty was experienced in obtaining good experimental results, except with iron. It was practically impossible to free iron completely from the hydrogen. Later, hydrogen was introduced into the metal electrolytically with essentially the same results.

Cailletet[6] and Troost and Hautefeuille[7] confirmed Graham's work by showing that hydrogen is retained by cast iron and by steel when heated in hydrogen to 1472 degrees Fahr. (800 degrees Cent.).

Determinations were made of the amount of gas liberated on reheating. Likewise, the work of Parry[8] showed that a low carbon steel (0.08 per cent carbon) heated in hydrogen to "a low red heat" absorbed a very appreciable amount of hydrogen, considerably more than was reported by Graham. Parry reported that the sample absorbed in 12 hours 5.1 times the volume of the specimen. The temperature was approximately that of the fusion point of copper, 1981 degrees Fahr. (1083 degrees Cent.). At a higher temperature 5.4 additional volumes were taken up.

Roberts-Austin was the first to attempt the study of the real rôle of hydrogen in iron by means of thermal analysis.[9] Electrolytic iron was used and was deposited from ferrous chloride directly on the bead of a platinum: platinum-iridium thermocouple. The deposit weighed 5 grams. He had previously shown that hydrogen is evolved at a relatively low temperature from electrolytic iron. The specimen was heated three times in vacuo to 2372 degrees Fahr. (1300 degrees Cent.), after which a photographically recorded cooling curve was taken by the differential method, the neutral body used being platinum. In addition to A_3 and A_2, two other "points" showing as evolutions of heat

[6]Cailletet, *Comptes Rendus*, 61, 850-852, 1865.

[7]Hautefeuille and Troost, *Comptes Rendus*, 76, 482-485, 562-566 (1873).

[8]Parry, John. Hydrogen and Carbonic Oxide in Iron and Steel. *Journal*, Iron and Steel Institute, 1881, pt. 1, 183-194.

[9]Roberts-Austen, Sir. Wm., 5th Report Alloys Research Com., *Proceedings*, Institute Mechanical Engineers, 1899, 42-74.

upon cooling were reported; one of considerable magnitude beginning at 908 degrees Fahr. (487 degrees Cent.), and a rather faint one beginning at 502 degrees Fahr. (261 degrees Cent.). It was stated that the "points" became much smaller after repeated heatings, but that the one at 908 degrees Fahr. (487 degrees Cent.) could be restored by recharging the iron with electrolytic hydrogen.

Heyn[10] extended Roberts-Austen's work by investigating the effect of hydrogen upon the mechanical properties of soft steel (0.05 per cent carbon, 0.37 per cent manganese), the hydrogen being introduced by heating the steel in an atmosphere of hydrogen at 1346 to 1832 degrees Fahr. (730 to 1000 degrees Cent.). The steel was then quenched directly from the hydrogen in water. Steel was reported to be rendered quite brittle by this treatment, as shown by the cracks developed at relatively large radii of curvature (130 degrees approximately) upon cold bending the specimens. Heyn also concluded that no unusual effects are produced if the steel is slowly cooled in the hydrogen or if it is quenched in water after being heated in hydrogen to a temperature below 1346 degrees Fahr. (730 degrees Cent.). He reported later (second reference cited) that soft iron wire rendered brittle, as above, gradually regained its ductility. However, after 250 days at room temperature, the hydrogen-treated iron was not the equal of similar wire quenched from the same temperature but not from a hydrogen atmosphere.

The work of Belloc,[11] confirmed by that of Boudouard,[12] is of interest in showing the rate of hydrogen evolution upon heating a low carbon steel (0.12 per cent carbon). He interpreted his results as showing that the evolution of hydrogen begins between 572 and 752 degrees Fahr. (300 and 400 degrees Cent.) and reaches a maximum at approximately 1112 degrees Fahr. (600 degrees Cent.). At 2192 degrees Fahr. (1200 degrees Cent.), however, all of the gas had not been removed. Boudouard concluded that the physical condition of the metal affected the rate of evolution of the gas, but in all cases the evolution began at "red heat".

[10]Heyn, E., Eisen und Wasserstoff, *Stahl und Eisen*, 20, 837 (1900); 21, 913 (1901).

[11]Belloc, G., Gaz occlus dans les aciers. *Comptes Rendus*, 145, 1280-1283 (1907), *Revue de Metallurgie*, 5, 469-488 (1908).

[12]Boudouard, O., Extraction des gaz contenus dans les metaux, *Comptes Rendus*, 145, 1283-1284 (1907); *Revue de Metallurgie*, 5, 69-74 (1908).

Baker's[13] results for 0.13 per cent carbon steel heated in vacuo indicated an evolution of hydrogen beginning below 752 degrees Fahr. (400 degrees Cent.) with a marked increase in rate at 1112 degrees Fahr. (600 degrees Cent.) and a second increase at 1448 degrees Fahr (787 degrees Cent.), the rate of evolution above this being much less. Baker determined the thermal transformations of his steel, but was unable to confirm Roberts-Austen's findings concerning the "hydrogen points" below A_2 in iron.

Charpy and Bonnerot[14] showed that the diffusion of hydrogen through iron is *nil* below 617 degrees Fahr. (325 degrees Cent.). Above this temperature the rate at which hydrogen can be passed through iron increases with the temperature. Under the conditions used by them, the rates were at 662 degrees Fahr. (350 degrees Cent.), 1.1 cubic centimeters per hour; 842 degrees Fahr. (450 degrees Cent.), 3.2; 1022 degrees Fahr. (550 degrees Cent.), 8.5; 1382 degrees Fahr. (750 degrees Cent.), 30.0; and 1562 degrees Fahr. (850 degrees Cent.), 42.0 cubic centimeters per hour. They also reported that iron through which hydrogen gas was diffused while being heated retained no more of the hydrogen than a similar piece of the metal simply heated in the hydrogen atmosphere.

Their hydrogen determination for iron (soft steel) through which hydrogen was passed for 210 hours at 1112 degrees Fahr. (600 degrees Cent.), indicated that 0.04 cubic centimeters of hydrogen was retained per gram of iron. The same metal simply heated in hydrogen under similar conditions of time and temperature showed 0.07 cubic centimeters hydrogen per gram of iron.

Harding and Smith[15] reported upon the length and electrical resistance changes resulting from cathodic occlusion of hydrogen in a number of metals, including iron, and suggested that the hydrogen existed in two forms, "alloy" hydrogen and "conducting" hydrogen. Fuller[16] has discussed very fully the penetration of iron by atomic (cathodic) hydrogen, and emphasized the

[13]Baker, Thomas. Gases Occluded in Steel. *Journal*, Iron and Steel Institute, *Carnegie Scholarship Memoirs*, 1, 219-229 (1909); 3, 249-259 (1911).

[14]Charpy, G., and Bonnerot, S. Sur la permeabilite du fer pour l'hydrogene, *Comptes Rendus*, 154, 592 (1912) and 156, 394 (1913).

[15]Harding, E. A., and Smith, D. P. Occlusion of Hydrogen and Oxygen in Metal Electrodes. *Journal*, American Chemical Society, 40, 1508-1531 (1918).

[16]Fuller, T. S. The Penetration of Iron by Hydrogen, *General Electric Review*, 23, 702 (1920).

difference in the behavior of nascent (atomic) hydrogen and gaseous (molecular) hydrogen on iron.

Pilling's[17] study of the effect of heat upon electrolytic iron indicated that the evolution of hydrogen begins below 212 degrees Fahr. (100 degrees Cent.) and reaches its maximum around 392 degrees Fahr. (200 degrees Cent.). Indication of another increase in the rate of gas evolution between 1112 and 1292 degrees Fahr. (600 and 700 degrees Cent.) was also obtained. A pronounced increase (over 75 per cent) in scleroscope hardness after heating at 482 degrees Fahr. (250 degrees Cent.) was noted for the material. With further heating the hardness gradually decreased until below its initial value.

Williams and Homerberg have recently pointed out[18] that the severity of the detrimental effect of "cathodic" hydrogen upon the ductility of soft steel depends upon the number and distribution of inclusions, oxides and sulphides, in the steel.

III. Materials and Method

1. Materials. Three materials similar to those used by Sirovich, open-hearth iron and electrolytic iron and low carbon steel were used for the work described below. The observations on the low carbon steel (0.07 per cent carbon) were obtained in a previous investigation.[19]

The open-hearth iron was in the form of a 2-inch round of the following composition: Carbon, 0.02 per cent; Manganese, 0.02 per cent; Phosphorus, 0.003 per cent; Sulphur, 0.027 per cent; and Silicon, 0.004 per cent. Most material of this kind contains a small amount of copper, approximately 0.03 per cent. Microscopic examination and supplementary determinations for "gas" content showed considerable variation in the oxygen content across the section of the bar. Results of the oxygen determinations are given in a later section.

The electrolytic iron was obtained from various lots of this material made at the Bureau at different times. Any unusual

[17] Pilling, N. B. Heat Treatment of Electrolytic Iron, *Transactions*, American Electrochemical Society, 42, 9 (1922).

[18] Williams, R. S., and Homerberg, V. O. Intercrystalline Fracture of Steel, Transactions, American Society for Steel Treating, 5, 399 (1924).

[19] See note "a," Table I.

feature in composition or preparation is noted along with the results obtained (Figs. 4 and 5).

2. Method. The behavior of the materials when heated and cooled in vacuo was studied by the method of thermal analysis. The thermal expansivity of bars of the materials was determined from room temperature up to approximately 842 degrees Fahr. (450 degrees Cent.). The X-ray method was also used for the study of the crystal structure of the iron before and after treatment with hydrogen. Chemical determinations for hydrogen and oxygen were also carried out.

(a) Thermal Analysis

The apparatus and general method have been described in a previous publication.[20] In brief, the method consists in determining the time required for a definite temperature change of the specimen, which is heated by being moved at a uniform controllable rate, from the cooler end of a rather long electrically heated tubular furnace toward the hotter end and in the opposite direction on cooling. The furnace is wound in such a manner that when heated, there is a decided, but uniform, temperature gradient from one end to the other. The results when plotted give the well known inverse-rate thermal curve.

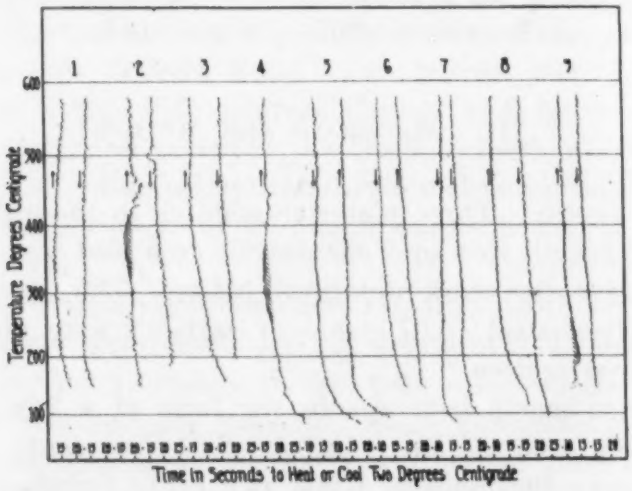

Fig. 2—Inverse-rate Thermal Analysis Curves of Open-hearth Iron. The Numbers Used are those Assigned in Table I, Where the Treatments Prior to Thermal Analysis are Given. The Shaded Areas for Nos. 2 and 4 Indicate a Heat Evolution on Heating; that for No. 9, an Absorption of Heat on Heating.

[20] Use of a Modified Rosenhain Furnace for Thermal Analysis, H. Scott and J. R. Freeman, Jr. Bureau of Standards, Scientific Paper 348 (1919).

(b) Thermal Expansion

It was in determinations of this kind that Sirovich made observations upon which he based his conclusions as to a transformation in iron at 698 degrees Fahr (370 degrees Cent.). The method used here has been described[21] elsewhere. It consists in the direct

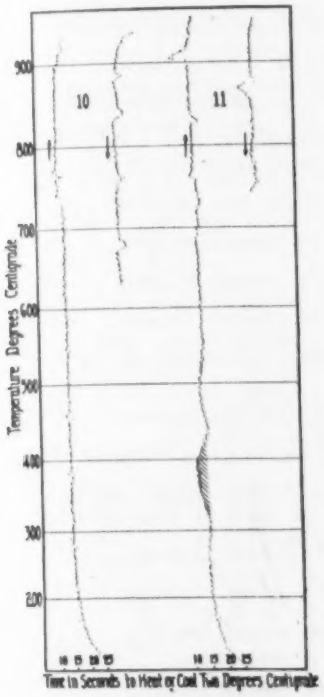

Fig. 3 — Inverse-rate Thermal Analysis Curves of Low Carbon Steel. The Initial Carbon Content was 0.07 Per Cent, the Absence of the A_1 Peak in the Curves Indicates Decarburization During the Treatment of the Steel, which is Summarized in Table I. No. 11 Showed a Heat Evolution During Heating.

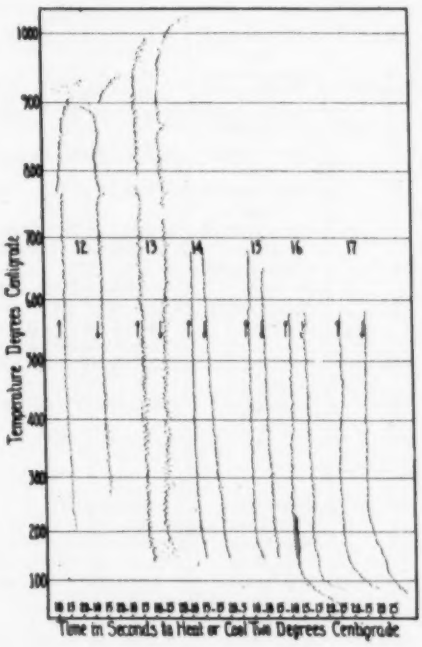

Fig. 4—Inverse-rate Thermal Analysis Curves of Electrolytic Iron. The Preliminary Treatments of the Specimens are Tabulated in Table I, the Numbers Correspond to those in Table I. Note the Heat Absorption in the Heating Curve of No. 16.

measurement of the length changes of a bar 30 centimeters long maintained for a sufficient length of time at the desired tmperature until the length remains constant.

IV. Results

1. Thermal Analysis

Any transformation, occurring "spontaneously" in a metal or alloy during heating or on cooling from an elevated temperature, if sufficient in magnitude to manifest itself as a volume

[21] Measurements on the Thermal Expansion of Fused Silica, W. Souder and P. Hidnert, Scientific Paper 524; Bureau of Standards, 1926.

Table I

Results of Thermal Analysis of Iron

B = beginning of heat change, M = maximum of heat change

Specimen No.	Material	Treatment Prior to Thermal Analysis	Thermal Characteristics, Shown by Heating Curve	Figure No.
1	Open-hearth Iron	Annealed 1 hr. 865° C., illuminating gas passed into furnace.	No pronounced unusual features.	2
2	Open-hearth Iron	2 hrs. 750° C. in commercial H_2.	Pronounced heat evolution. B=300° C., M=380° C.	2
3	Open-hearth Iron	2 hrs. 750° C. in commercial N_2.	No pronounced unusual features.	2
4	Open-hearth Iron	2 hrs. 975° C. in *dry* H_2.	Heat evolution, M=300° C.	2
5	Open-hearth Iron	5 hrs, 950° C., *dry* H_2.	Slight heat evolution (?) above 300° C.	2
6	Open-hearth Iron	2 hrs. 750° C., moist H_2.	No unusual features.	2
7	Open-hearth Iron	2 hrs. 850° C., dry H_2, quenched in cold water.	No unusual features.	2
8	Open-hearth Iron	2 hrs. 975° C., dry H_2, quenched in cold water.	No unusual features; see cooling curve, however.	2
9	Open-hearth Iron	Cathode in electrolytic cell, 2% H_2SO_4,[d] 18 hrs. room temperature.	Heat absorption, M=200° C.	2
10[a]	0.07% C Steel	1 hr. 1000° C., dry N_2.	No unusual features.	3
11[a]	0.07% C Steel	1 hr. 1000° C., dry H_2.	Heat evolution.[b] M=390° C. Ac_1 nearly "wiped out," as a result of decarburization by H_2.	3
12	Electrolytic Iron	As deposited.[c]	No unusual features.	4
13	Electrolytic Iron	Deposited directly on the bead of thermocouple.	No unusual features.	4
14	Electrolytic Iron remelted	2 hrs. 750° C., moist H_2.	No unusual features.	4
15	Electrolytic Iron remelted	22 hrs. as cathode in electrolytic cell, H_2SO_4, room temperature.[d]	No unusual features.	4
16	Electrolytic Iron remelted	48 hrs. as cathode in electrolytic cell, H_2SO_4, room temperature.[d]	Heat absorption, B=100°, M=225° C.	4
17	Electrolytic Iron	As deposited, crushed and heated 5 hrs. 950° C., dry H_2, briquetted into form for specimen.	No heat evolution.	4
18	Electrolytic Iron	Completely oxidized, reduced with dry H_2, briquetted, heated 2 hrs. 950° C., dry H_2.	Heat evolution, M=325° C.	5
19	Electrolytic Iron	As above except the run was made *directly* after reduction in H_2, with no further treatment.	Heat evolution, M=310° C.	5
20	Electrolytic Iron	Material similar to above was melted in vacuo, and heated in dry H_2 975° C. 2 hrs.	Heat evolution, M=290° C.	5

[a] From an unpublished Bureau of Standards investigation, H. J. French, T. G. Digges, and H. C. Cross, Effect of Character of Furnace Atmosphere in the Annealing of Steel.

[b] Three runs were made; two showed this feature.

[c] The iron was deposited in July, 1924; the thermal curve was taken April, 1925.

[d] Specimens were of approximately the same size and all were run under the same conditions.

change localized within a very short temperature range would be expected because of the fundamental energy change involved, to be detectable as a thermal "transformation point". The thermal analysis method, therefore, because of the relative ease with which such determinations can be carried out as well as for the accuracy of the results obtained, was given preference in the study of the material in which the reported 698 degrees Fahr. (370 degrees Cent.) transformation might be expected to occur.

In Table I are summarized the materials used, the treatment given each before being used for thermal analysis and the principal thermal characteristics in the lower part of the curve, as shown by the heating curve. In general, any unusual effect when noted, occurred during the heating only. The curves obtained are given in Figs. 2 to 5 inclusive.

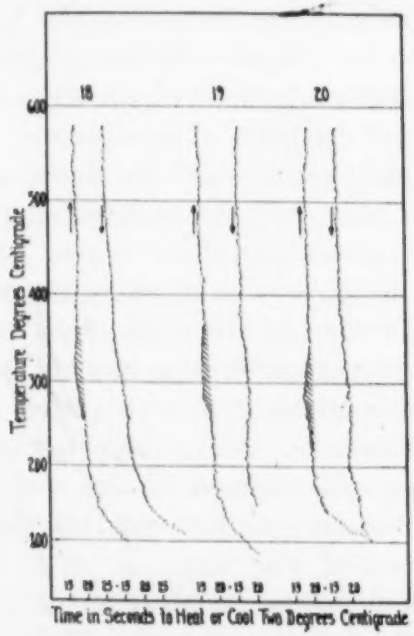

Fig. 5—Inverse-rate Thermal Analysis Curves of Electrolytic Iron Completely Oxidized and then Reduced with Hydrogen. See Table I for the Complete Treatment. Note the Heat Evolution Shown by the Heating Curve for Each of the Specimens.

The results summarized in the table and curves show that iron treated with hydrogen, by being heated in such an atmosphere, at times exhibits an irregularity in the heating curve of the treated metal. This feature reveals itself, as an evolution of heat, in most cases spread over a considerable temperature range, but usually showing a maximum somewhere around 572 degrees

Fahr. (300 degrees Cent.). This feature is by no means invariably found in iron specimens which have been heated in hydrogen, and is therefore not at all characteristic of a true transformation. In the curves (Figs. 2 to 5) in which this feature was unmistakable, the area corresponding to it has been shaded. Suggestion of the same feature may be seen in some of the other curves, but the majority of the thermal curves taken did not show this irregularity. It was found more frequently in the open-hearth iron used than in electrolytic iron given identical treatment.

No indications were obtained which would show that the presence of traces of moisture or oxygen in the hydrogen used would in any way account for the phenomenon observed. The hydrogen was used in three different states of purity, (a) as taken directly from the commercial cylinder of compressed gas, (b) the same as (a) saturated with water vapor by bubbling through distilled water, and (c) the same gas as (a) freed from traces of oxygen by passing it over platinized silica heated to redness and then completely drying it by means of phosphorus pentoxide.

The material for some of the runs, (Nos. 7 and 8, Table I and curve 3, Fig. 8) was prepared by a method described by Heyn[22] of quenching the iron directly in water after it has been heated in a hydrogen atmosphere. Heyn reported that an appreciable amount of hydrogen was retained by the iron after such a treatment. The apparatus and method used in the present work are shown in the diagram of Fig. 5.

One definite conclusion which the results of thermal analysis warrant is that iron treated with hydrogen by being made the cathode of a suitable electrolytic cell behaves very differently from iron treated with hydrogen gas at a higher temperature. When the cathode specimen is heated, the heating curve indicates an absorption of heat which begins not far above room temperature and is completed somewhat above 392 degrees Fahr. (200 degrees Cent.). This absorption of heat, in all probability, is a necessary condition for accomplishing the escape of the hydrogen "occluded" by the iron during the electrolytic process. The observations of Pilling[23] on the same phenomenon by an entirely different method confirm the result obtained here, at least so far as location of the temperature range in which the phenomenon

[22]See Note 10.

[23]See Note 17.

occurs is concerned. The results obtained with the two materials, open-hearth iron and electrolytic iron, treated with hydrogen electrolytically, indicated a difference in the response of the two materials to the hydrogen treatment. Easily detectable results were obtained with the open-hearth iron in a shorter time than with electrolytic iron (specimens 9, 15 and 16, Table I). This feature may be related to observations of Williams and Homerberg[24] upon which they based their conclusion that the increase in brittleness of iron under the influence of cathodic hydrogen is dependent in large measure upon the inclusions in the iron. The oxygen content of the open-hearth iron used was considerably higher than that of the electrolytic iron.

In no case did the results of thermal analysis of either material confirm those reported in the work of Roberts-Austen[25] on electrolytic iron as to the transformation points below A_2 showing as evolutions of heat upon cooling.

On the whole, the curves for the open-hearth iron indicated a more noticeable tendency for this material to exhibit an irregularity in the heating curve than did the electrolytic iron (compare Figs. 2 and 4). In the case of the electrolytic iron which had been completely oxidized and then reduced with hydrogen, the heat evolution upon heating was obtained (Fig. 5). This material when fused in vacuo and subsequently heated in hydrogen, also gave evidence of the heat evolution on heating in the thermal analysis run (Fig. 5, curve 20). The microscopic examination of this specimen showed a structure quite similar to that of open-hearth iron, that is, numerous oxide inclusions in the iron were to be seen (Fig. 11).

2. *Thermal Expansion*

All of the results reported below in graphical form were obtained upon two specimens, one of open-hearth iron and one of electrolytic iron. The various treatments used were applied in succession to the same bar, thus possible variations in results by reason of differences other than treatment were eliminated. The open-hearth iron specimen was cut from one quadrant of a cylindrical bar of 2-inch diameter. The electrolytic iron specimen

[24] See Note 18.

[25] See Note 9.

was a bar forged from a small ingot of remelted electrolytic iron. Another bar from the same ingot had been used previously in the determination of thermal expansion.[26] The composition

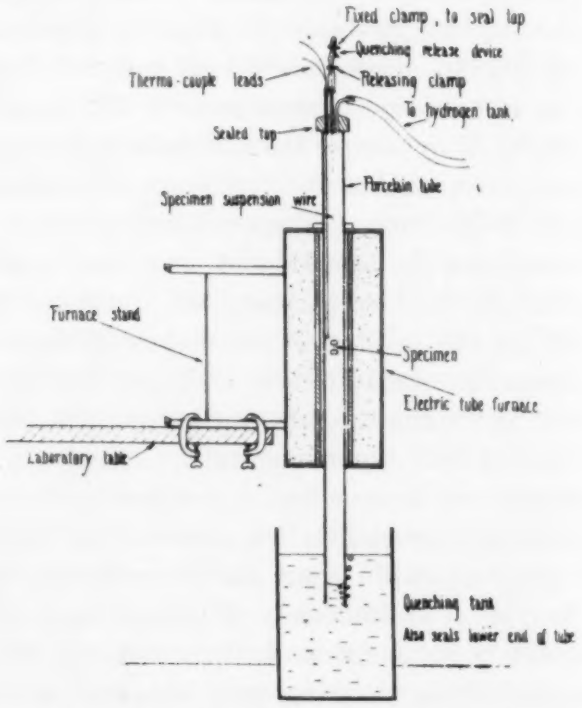

Fig. 6—Apparatus Used for Quenching Specimens in Water Directly from the Hydrogen Atmosphere in which they were Heated.

of this material was: carbon, 0.02 per cent; sulphur, 0.007 per cent; silicon, 0.006 per cent; manganese and phosphorus, nil; cobalt, copper and nickel together, 0.014 per cent.

The expansion of each bar from room temperature to 842 degrees Fahr. (450 degrees Cent.) was measured. The results obtained, together with the various treatments used for the bars, are summarized in Figs. 6 to 9. In the temperature range, 617 to 752 degrees Fahr. (325 to 400 degrees Cent.) approximately, expansion measurements were taken at short intervals (3 or 4 degrees) since it was within this temperature range that the transformation had been reported by Sirovich. It will be noted that some of the curves show an "irregularity" in the expansion of the material within this temperature interval which was examined in detail. While none of the irregularities can be classed

[26]Souder, W., and Hidnert, P. Thermal Expansion of a Few Steels, Bureau of Standards Scientific Paper 433 (1922), Fig. 2.

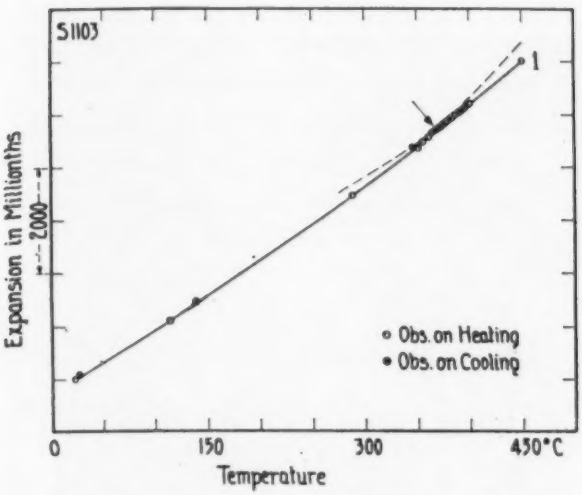

Fig. 7—Thermal Expansion Curve of Open-hearth Iron from Room Temperature to 842 Degrees Fahr. (450 Degrees Cent.). The Bar was Annealed Prior to the Expansion "Run" in the Open Furnace, in which Illuminating Gas was Burned. Note the Irregularity in the Curve between 662 and 752 Degrees Fahr. (350 and 400 Degrees Cent.), Represented Above by Two Intersecting Curves.

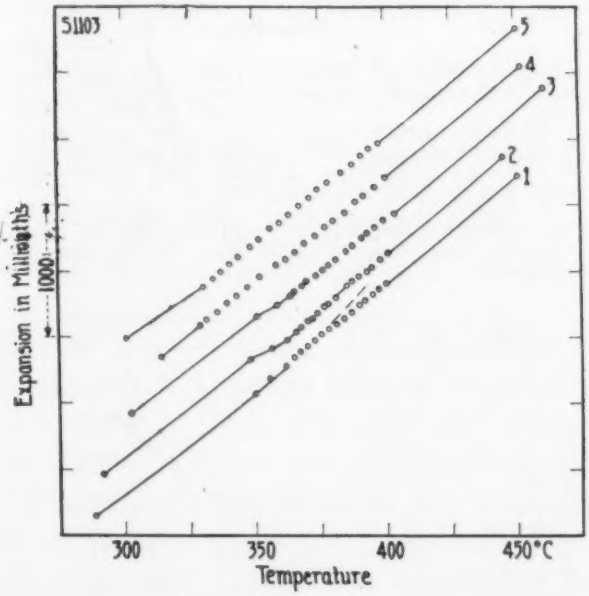

Fig. 8—Thermal Expansion Curves of an Open-hearth Iron Specimen After Different Successive Treatments.

1. Same Curve as Fig. 6.
2. Heated in Commercial H_2, 2 Hours, 1382 Degrees Fahr. (750 Degrees Cent.); Cooled in H_2.
3. Heated in Vacuo, 1 Hour, 1577 Degrees Fahr. (825 Degrees Cent.), Cooled in Vacuo.
4. Heated in Moist H_2, 2 Hours, 1382 Degrees Fahr. (750 Degrees Cent.), Cooled in H_2. The Current of H_2 was Maintained to 608 Degrees Fahr. (320 Degrees Cent.), then Cut Off.
5. No Additional Treatment. This Run was Made Immediately After 4.

as "pronounced" or "abrupt", as is to be expected in a true transformation, the "irregularity" could not be disregarded in drawing the expansion curve. In one case, (curve 1, Fig. 8) the results could best be expressed as two curves intersecting at 698 degrees Fahr. (370 degrees Cent.) (approximately). A compar-

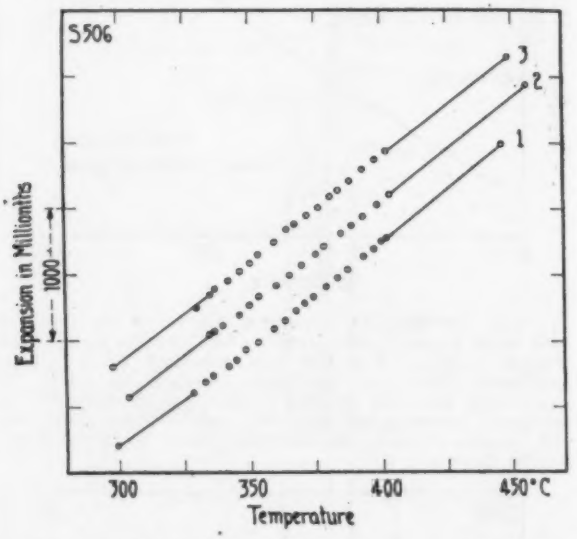

Fig. 9—Thermal Expansion Curves of Electrolytic Iron After Different Successive Treatments of the Same Bar.

1. Heated in Commercial H_2, 2 Hours, 1382 Degrees Fahr. (750 Degrees Cent.), Cooled in H_2.
2. Heated in Moist H_2, 2 Hours, 1382 Degrees Fahr. (750 Degrees Cent.), Cooled in H_2.
3. Heated in H_2, Previously Dried and Freed from O_2, 3 Hours, 1742 Degrees Fahr. (950 Degrees Cent.), Quenched Into Water Directly from the Hydrogen Atmosphere.

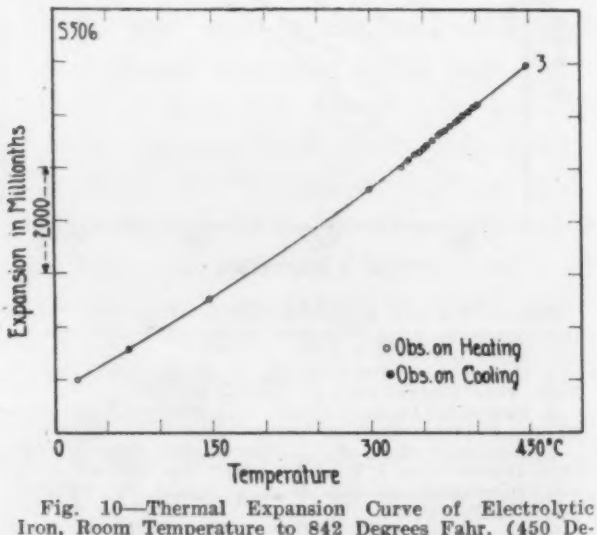

Fig. 10—Thermal Expansion Curve of Electrolytic Iron, Room Temperature to 842 Degrees Fahr. (450 Degrees Cent.). Same as No. 3, Fig. 8.

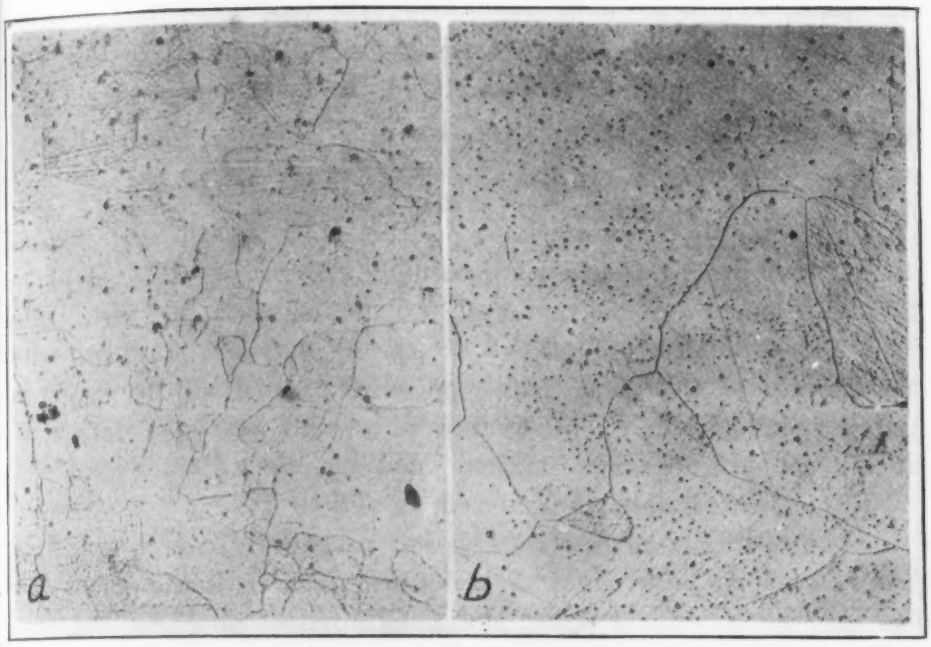

Fig. 11—Microstructure of Ferrite. Magnification 100 x. Etched with 2 Per Cent Nitric Acid.
a, Open-hearth Iron.
b, Electrolytic Iron, Fused in Vacuo After Being Completely Oxidized and then Reduced with Hydrogen.
Note the Inclusions of Oxide in Both Materials.

ison of the relative magnitude of the observed irregularity in expansion with that of the transformation reported by Sirovich can not be made since in the published curves by Sirovich, the ordinates, representing expansion, are not expressed in definite units.

The results of the expansion determinations confirm those of the thermal analysis in showing that an irregularity may occur in the thermal curves of iron and that the irregularity is not a constant one, that is, it is not one that invariably repeats itself. Although the results check the work of Sirovich to the extent of showing some deviations from the "smooth" expansion curve, they do not, in any way, confirm his conclusion concerning the reported allotropic transformation.

The expansion curves, Figs. 7 and 10, suggest that, of the two materials used, the open-hearth iron is more prone to irregularity in expansion than is the remelted electrolytic iron. There is also some indication that in a series of "runs" on the same bar, those later in series are apt to show greater regularity in the expansion than the early runs. Of the five curves taken on the

specimen of open-hearth iron, the first run after the hydrogen treatment (curve 2, Fig. 8) was noticeably more irregular than later ones, although the treatment of the specimen was essentially the same.

3. *Determinations of Oxygen and Hydrogen*

Microscopic examinations of the open-hearth material had shown that it contained an appreciable amount of oxide, as judged by the number and character of the inclusions in the metal (Fig. 11). The distribution of the inclusions was not uniform across the section of the bar. Analyses were carried out to determine the oxygen content. The hydrogen content was also determined at the same time. The method used has been described.[27] The results obtained are summarized in Table II.

The results suggest strongly that, inasmuch as iron which has been heated in hydrogen, may contain less of this element than the iron in its initial state, the irregularities noted in the properties of the iron upon heating are not to be attributed, simply and wholly, to the presence of hydrogen. The average oxygen content of the untreated iron (determinations 1 to 5 inclusive) was 0.052 per cent, a value which agrees fairly closely with that of the vacuum-annealed material. Both of the hydrogen-treated

Table II
Oxygen and Hydrogen Content of Open-Hearth Iron[a]

Determination Number	Condition of Specimen	Location of Specimen	Oxygen, Per Cent	Hydrogen, Per Cent
1	As cut from bar.	Not recorded.	0.047	0.0009
2	As cut from bar.	Not recorded.	0.083	0.0011
3	As cut from bar.	Edge of cross section of 2-inch bar.	0.030	0.0008
4	As cut from bar.	Center of 2-inch bar.	0.072	0.0005
5	As cut from bar.	Edge of 2-inch bar.	0.028	nil
6	Heated 2 hrs. in hydrogen, 750° C., cooled in hydrogen.	Not recorded.	0.046	nil
7	Heated 2 hrs. in hydrogen, 750° C., cooled in hydrogen.	Not recorded.	0.040	0.0001
8	Heated in vacuo, 850° C.	Not recorded.	0.058	0.0004

[a]Bureau of Standards analysis, L. Jordan, Chemist, and W. P. Barrows, Associate Chemist.

[27]L. Jordan and J. R. Eckman. Gases in Metals, II: Determination of oxygen and hydrogen in metals by fusion in vacuum, Bureau of Standards Scientific Papers No. 514.

irons (No. 6 and 7, Table II) were appreciably below this value in their oxygen content. The obvious conclusion that the hydrogen serves, first of all, to reduce the oxide to metallic form would appear to be the correct one. The variation in oxygen content of the original material is so wide that deductions based on the average oxygen content can be taken as suggestive only, not as definite proof. The possible relation of this phenomenon to the observed irregularities in the "thermal characteristics" of the iron is referred to later.

4. Crystal Structure—X-ray Examination

It has been well established by investigators of the crystal structure by means of the X-ray diffraction method that in iron in the alpha condition, that is, below 1652 degrees Fahr. (900 degrees Cent.) (approximately), the atoms are arranged according to the body-centered cubic packing. Davy[28] has reported the lattice constant of alpha iron, that is, the length of the side of the unit cube, to be 2.855 ± .003 Angstrom units. No difference was reported by him in this "constant" for electrolytic iron fused in vacuo (Carbon 0.02 per cent, Manganese 0.001 per cent, Phosphorus 0.004 per cent, Sulphur 0.017 per cent and Silicon 0.021 per cent) and for iron made by reducing ferric oxide with hydrogen.

Measurements of this kind were also made[29] on a sample of electrolytic iron (unfused) crushed and sifted through 200-mesh bolting cloth and the same iron oxidized to free it from carbon and other impurities and then reduced by hydrogen.[30] The open-hearth iron in its initial condition was also examined. Its pattern was found to be identical with that of the electrolytic iron. The unfused electrolytic iron would be expected to contain more hydrogen than in the same material after fusion, as in Davy's experiments. The iron reduced from the oxide by hydrogen (specimen 19, Table I) was used directly after the reduction. The diffraction patterns of the two materials were identical so far as the spacing of the bands was concerned. The computed value of the lattice constant was 2.852 Angstrom units, a value which is in good agreement with that reported by Davy. Nothing was

[28] Davy, W. P. Precision Measurements of the Lattice Constant of Twelve Common Metals, *Physical Review*, 25, 753 (1925).

[29] F. Sillers, Scientific Aid, Bureau of Standards.

[30] Prepared by L. Jordan, Bureau of Standards.

noted which would indicate a change in the atomic spacing attributable to hydrogen.

A decided difference was noted, however, in the number of bands in the diffraction patterns of the two irons. The pattern produced by the electrolytic iron in its initial state was somewhat less intense than that of the hydrogen-reduced iron taken under identical conditions, also it faded out much more quickly, that is, with increasing angle of diffraction. In the diffraction pattern of the iron reduced by hydrogen 12 distinct bands could be distinguished, whereas in the pattern of the electrolytic iron only 8, with certainty. Davy's published results also indicate a similar difference. His results show that he was able to count 11 bands in one of the patterns of this hydrogen-reduced iron, but the presence of only 7 in the pattern of the fused electrolytic iron could be established with certainty. These pattern differences may be interpreted as indicating a *very* much finer grain size in the iron reduced by hydrogen from the oxide than in the other material, despite the fact that both had been crushed fine enough so as to pass through 200-mesh bolting cloth.

V. Discussion

The results of the examinations carried out have confirmed the work of Sirovich to the extent of showing an irregularity in the thermal behavior of iron as revealed by expansion measurements as well as by the thermal analysis method. The "irregularity" is of such a character, however, that the explanation offered by Sirovich, that it is to be attributed to a polymorphic transformation in the iron, does not at all appear to be justified. The definite manner in which a true transformation repeats itself in succeeding "runs" was entirely lacking in this instance. In the thermal analysis, the "irregularity" manifested itself as a slight evolution of heat during the heating of the specimen, the maximum of which was usually somewhere around 572 degrees Fahr. (300 degrees Cent.).

Prompted by the reports on the effect of hydrogen gas upon the properties of iron which have been made by various investigators, as well as by some suggestive results obtained previously in another Bureau investigation along this line (Table I, note "a"), the authors attempted to connect the observed irregularity in the thermal characteristics of the iron with the influence of

hydrogen on the iron. The results indicated that the phenomenon was much more likely to occur in iron which had been heated and cooled in hydrogen than in iron which had not received such a treatment, as, for example, in vacuum-annealed iron. Hydrogen-treated iron showed the phenomenon only occasionally, however, and not invariably. There was also some suggestion in the expansion curves of a "dying-out" of the phenomenon in succeeding runs on the same specimen, the preliminary treatment of which was essentially the same.

Iron quenched in water after being heated in hydrogen, the quenching being carried out *directly* from the hydrogen atmosphere, showed no greater tendency toward the phenomenon than iron merely heated and cooled in the hydrogen atmosphere. Heyn[31] had previously concluded that such a treatment would cause enough hydrogen to be retained in the iron to modify its mechanical properties very materially.

Thermal analysis showed definitely that the effect of "cathodic" hydrogen in iron, that is, hydrogen taken up and retained by the iron when made the cathode of an electrolytic cell (dilute sulphuric acid in this instance) is distinctly different in its effects on the heating curve from the irregularity under discussion. Specimens of each of the two kinds of iron used, when charged with "cathodic" hydrogen showed an absorption of heat upon being heated. The absorption began not far above room temperature and was completed somewhat above 392 degrees Fahr. (200 degrees Cent.) whereas the other effect, when it appeared, manifested itself as an evolution of heat at a distinctly higher temperature.

Chemical determinations of the "gas content" of the open-hearth iron used indicated an appreciable amount of oxygen, somewhat variable according to the position in the bar of the sample used, and also a detectable amount of hydrogen. The same material after being heated in an atmosphere of hydrogen in the same manner as in the other tests, showed no more hydrogen than the iron in its initial state or after having been annealed in vacuo. The average oxygen content of the iron after the hydrogen treatment, was probably somewhat lower than before. The conclusion that the irregularity noted in the thermal behavior of iron is not a direct result of the simple presence of

[31] Footnote 10.

hydrogen, as such, in the iron would seem to be warranted. It was observed that the specimens of iron prepared by reducing iron oxide by means of hydrogen behaved most consistently of all the materials used so far as the repetition of the phenomenon under discussion in successive runs is concerned. This suggests the possible dependence of this phenomenon upon some condition resulting from the presence of iron oxide in the iron. The hydrogen-reduced iron after fusion in vacuo (Specimen 20, Table I), also was found to show the irregularity in its heating curve. The material, upon microscopic examination, however, showed numerous iron oxide inclusions in its microstructure perhaps on account of incomplete initial reduction, and hence was in essentially the same condition as the open-hearth iron and might show the phenomenon for the same reason.

The peculiar condition in iron containing appreciable amounts of iron oxide conducive to the occurrence of the observed "irregularity" in the thermal behavior of the material which might result from treatment with hydrogen may perhaps be of the same nature as that revealed by the X-ray examination of iron prepared by reduction of the oxide. As previously stated, the study of the crystal structure of the iron, by means of the X-ray diffraction method gave results which differed materially in one essential respect for iron reduced by hydrogen from oxidized electrolytic iron and the same iron in its initial, or untreated, state. The difference, which was essentially in the number of the bands in the diffraction patterns produced under identical conditions, was interpreted as one of grain size. Hydrogen-reduced iron, according to this interpretation, has a very much finer grain than iron in the ordinary condition. In this respect, it resembles the finely divided metals prepared by reduction of metallic oxides at low temperatures.[32] Wyckoff and Crittenden[33] found in their study of iron oxide catalysts (Fe_3O_4) when reduced with hydrogen that "whereas the individual crystals of fused magnetite are very large (at least several millimeters long) the crystalline iron produced by reduction (with hydrogen) is always so fine-grained that no grinding is needed to give a perfect powder photograph."

[32]Tammann, I. G., and Nikitin, N. L. Pyrophoric Properties of Finely Divided Metals. *Journal*, Russian Physical Chemical Society, 56, 115-9 (1925). *Chemical Abstracts*, 19, 3042, (1925).

[33]Wyckoff, R. W. G., and Crittenden, E. D. An X-ray Examination of Some Ammonia Catalysts. *Journal*, American Chemical Society, 47, 2867 (1925).

They also obtained evidence of pronounced grain growth upon reheating the hydrogen-reduced pure iron. This is in line with Jeffries and Archer's[34] discussion of recrystallization of fine metal powders upon heating. They have shown that grain growth may be obtained even in briquets of sintered metal powders as free from strain as possible. The recrystallization of such very finely divided metal upon heating might be expected to be accompanied by an evolution of heat. Whether this would be pronounced enough to be detected by the methods used would depend upon the relative amount and distribution of the fine-grained iron in the sample under observation. Tammann and Nikitin have set 698 degrees Fahr. (370 degrees Cent.) as the approximate recrystallization temperature for finely divided iron made by the reduction of the oxide, the conclusion being based upon a study of the pyrophoric characteristics of iron prepared under different conditions.

Summary

1. The results of the investigation do not confirm the conclusion reported by Sirovich as to a polymorphic transformation in ferrite at 698 degrees Fahr. (370 degrees Cent.), although they do indicate an "irregularity" in the behavior of iron when heated at about this temperature.

2. This irregularity was shown by both thermal analysis (the inverse rate method), and by thermal expansivity measurements. The phenomenon, when it does appear in thermal analysis manifests itself as an evolution of heat upon heating, spread over a temperature range of 100 degrees or so and showing its maximum around 572 degrees Fahr. (300 degrees Cent.).

3. Iron treated with hydrogen by being heated to a relatively high temperature in an atmosphere of hydrogen and then cooled within the same atmosphere exhibits a greater tendency toward this phenomenon than does similar iron not subjected to the hydrogen.

4. Open-hearth iron, after being heated in hydrogen appears to have a greater tendency for this phenomenon to occur than electrolytic iron treated in a similar manner. Iron produced by reduction of the oxide by means of hydrogen showed the most pronounced tendency of any of the materials examined.

[34] Jeffries, Z., and Archer, R. S. The Science of Metals, p. 133, McGraw-Hill Book Co., 1924.

5. Iron charged with hydrogen by being made the cathode in a suitable electrolytic cell shows an *absorption* of heat when heated. The reported transformation in ferrite is associated with an *evolution* of heat and occurs at a distinctly higher temperature.

6. The open-hearth iron used was found to have a very appreciable but variable oxygen content, according to the position of the sample in the bar. Detectable amounts of hydrogen were also found in this material, the amount in the iron after being heated in hydrogen was no greater than in the iron in its initial state. The conclusion seemed to be warranted that the irregularity observed in the thermal characteristics of the iron was not to be attributed simply and wholly to the presence of hydrogen, as such, in the iron.

7. Examination of the crystal structure by X-ray of iron prepared by reduction of the oxide by hydrogen indicated a very much finer grain size for such material than for iron in the ordinary condition.

8. A possible explanation suggested for the heat-evolution in the neighborhood of 698 degrees Fahr. (370 degrees Cent.) occasionally observed during the heating of iron is the recrystallization of very fine-grained metal such as might result on reduction of iron oxide by hydrogen. The temperature of 698 degrees Fahr (370 degrees Cent.) has been set, independently, by previous investigators as the recrystallization temperature of very finely divided iron obtained by the reduction of oxide by hydrogen. The greater oxide content in the open-hearth iron as compared with electrolytic is in agreement with the more pronounced tendency for this material to show the "698 degrees Fahr. (370 degrees Cent.) irregularity".

This investigation was undertaken upon a suggestion made by Dr. H. W. Gillett, Chief of the Division of Metallurgy, and his advice and criticism as the work has progressed have been very helpful.

The authors wish also to thank H. C. Cross for the help given in carrying out a number of the thermal analyses reported and to W. T. Sweeney for assistance in the expansion tests.

HARDNESS AND TOUGHNESS OF HIGH SPEED STEEL AS AFFECTED BY HEAT TREATMENT

By Robert K. Barry

Abstract

The physical properties of high speed steel can be rather closely controlled by the manner of heating, cooling, tempering and drawing.

A survey of the available work on this subject leaves many possible questions unanswered. It seemed desirable then to complete a series of tests covering those heat treatments with which the author was familiar.

The results of these tests are offered in this paper.

Material

A POLISHED cold drawn drill rod 0.072 inch in diameter was used in making these tests. The analysis was carbon 0.70 per cent, tungsten 17 to 18 per cent, vanadium 1 per cent, chromium 3.50 per cent.

Preparation of Material

A separate rod furnished the material for each one of the ten distinct investigations. For example—Fig. 1 covers five different hardening heats. In preparing the test pieces for Fig. 1, four adjacent pieces 2 inches long were cut from the rod and the four pieces were put into a bundle. This operation was repeated until five bundles had been prepared. Forty inches of rod was required for the data given in Fig. 1.

Method of Test

The method of material preparation just outlined furnishes a maximum number of test pieces from each short rod with a negligible variation in condition and composition. The four pieces in any bundle will receive exactly the same heating, cooling and drawing, a condition of uniformity seldom encountered in other methods of testing. Hardness and deflection values for each one of the four pieces in any bundle were uniform and were averaged to give the value for the bundle or heat treatment. Fifty bundles (200 pieces) were tested, and of this number thirty bun-

A paper presented before the Cleveland Convention of the Society, September, 1925. The author, Robert K. Barry, is in charge of heat treating, Barry Company, Muscatine, Iowa.

dles (120 pieces) had a deflection variation of less than 0.010 of an inch for each one of the four pieces in any bundle.

A comparison of the variations for any one heat treatment with those resulting from impact tests proved interesting, the latter showing a marked variation for the several test pieces used for any test, and inconsistent results with changes in heat treatment, the length of impact test specimens increases the variation

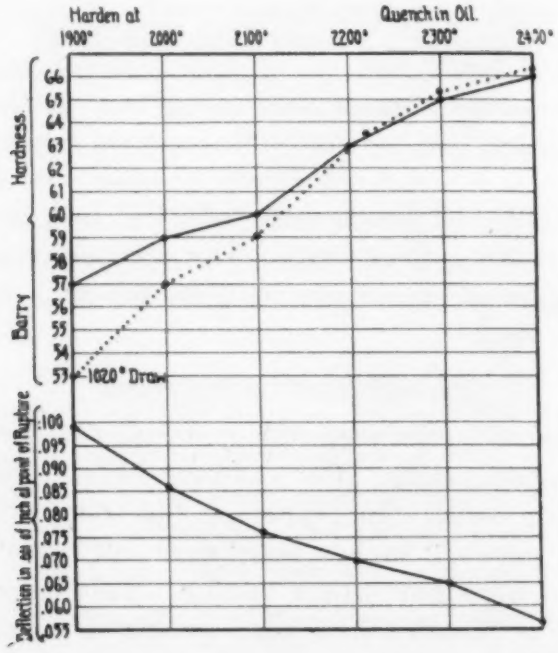

Fig. 1—Hardness and Deflection Curves Showing the Effect of Hardening Temperature on High Speed Steel. No Draw Except as Noted.

of the physical and chemical condition. This, together with the difficulty of separately hardening, quenching and drawing several pieces exactly alike, may, in part, account for the wide discrepancies encountered when making impact tests.

Deflection tests were made with a slow bending machine in which the 2-inch long test piece was supported near each end during the uniform application of pressure at the center of the piece. The amount of deflection was indicated in 0.001 of an inch on a drum integral with the camshaft of the machine. Readings were taken at the instant of rupture, which was apparent by the snap. Hardness tests were made with a Barry hardness tester—Values are similar to Rockwell—C.

Precautions

In addition to the usual precautions observed in conducting tests of this nature, a preliminary study was made of the time element in the high heat to assure the full hardening effect for each temperature used. The frequency with which we find a decided loss in hardness after a high draw indicates the importance of the time factor.

The opinion persists that inferior tool performance can more frequently be attributed to insufficient time in the high heat, and not to oversaturation.

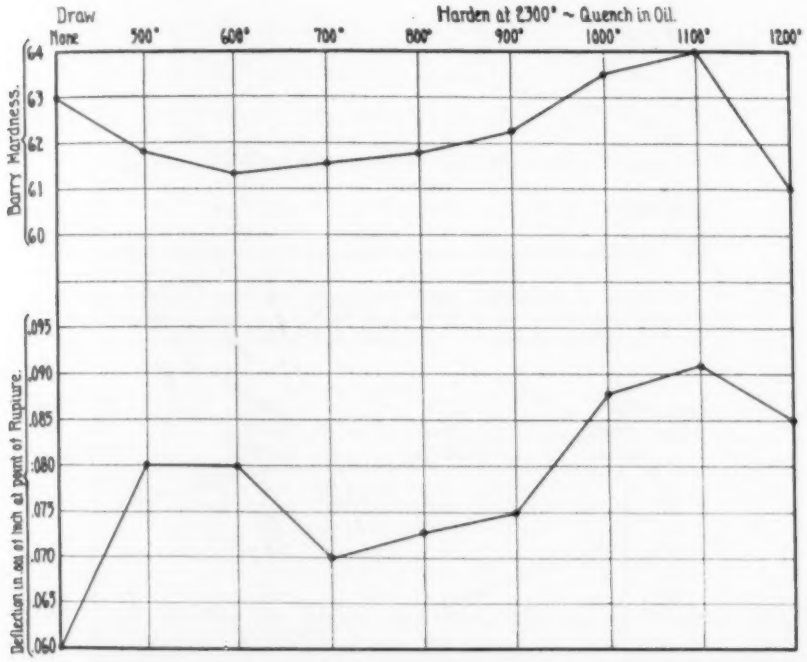

Fig. 2—Hardness and Deflection Curves Showing the Effect of Tempering Temperatures on Steels Oil Quenched from 2300 Degrees Fahr. Drawn as Shown.

In respect to the data shown in Fig. 1, it will be noted that the initial hardness increases as the quenching temperature is raised from 1900 to 2400 degrees Fahr. The dotted line indicates the effect of a high draw on steels hardened at the temperatures noted, and shows the absence of secondary hardness when quenching from low temperatures. It is interesting to note the rapid increase in the initial hardness when quenching from above 2100 degrees Fahr. The deflection or toughness decreases as the quenching temperature is raised, rapidly at first and then more slowly. At 2300 degrees Fahr. the rate again increases rapidly.

Fig. 2 shows the effect of drawing temperatures on steels oil-quenched from 2300 degrees Fahr. Thirty-two pieces were hardened at one time and then drawn as shown. The 1100 degree Fahr. draw produced maximum hardness and deflection. The 600-degree Fahr. draw resulted in the lowest hardness. The

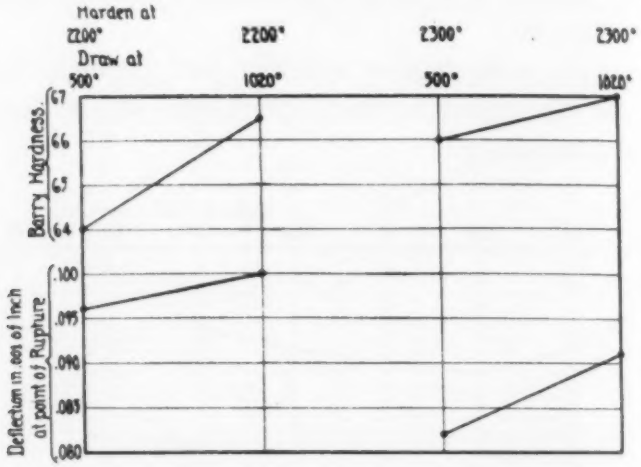

Fig. 3—Hardness and Deflection Curves Showing a Comparison Between a 2200 and a 2300 Degree Heat, Oil Quench, When Drawed at 500 and 1020 Degrees Fahr.

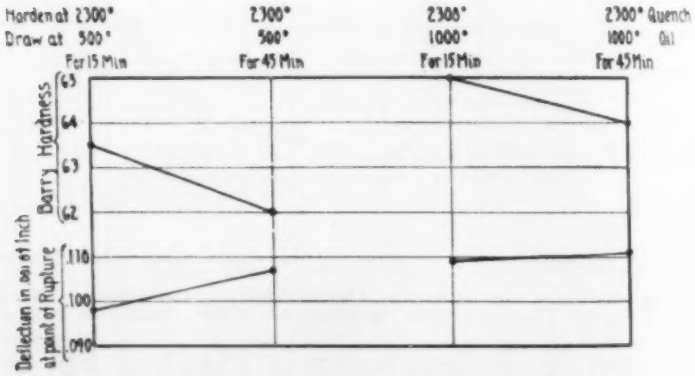

Fig. 4—Hardness and Deflection Curves Showing the Effect of Variation in Drawing Time After Hardening from 2300 Degrees Fahr. in Oil.

lowest deflection followed a 700-degree Fahr. draw. Drawing to 600, 700 and 800 degrees Fahr, gave generally poor results.

It would seem as though a distinct difference obtains between the effect of the softness produced by a 600 and a 1225-degree Fahr. draw. Effect of variations in the drawing time and temperature on steels oil-quenched from 2300 degrees is shown in Fig. 4. The deflection test value for the 1200-degree Fahr. draw should be

checked by other investigators, as it is agreed with and disputed by impact tests.

Fig. 3 shows a comparison between a 2200 and a 2300-degree Fahr. high heat oil-quench when drawing at 500 and 1020 degrees Fahr.

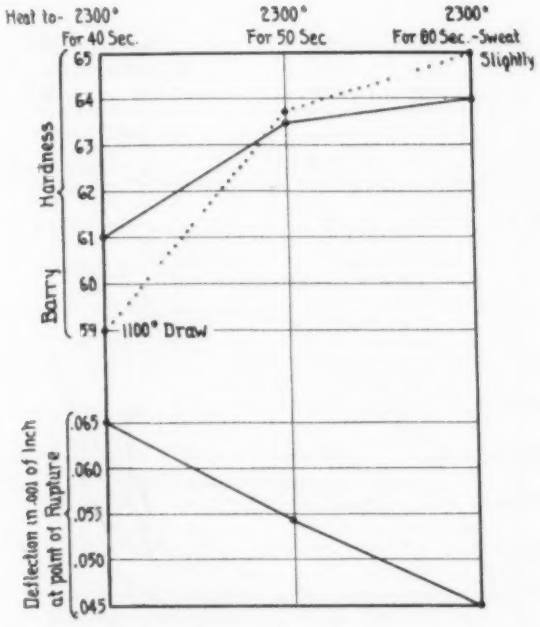

Fig. 5 — Hardness and Deflection Curves Showing the Effect of Time at 2300 Degrees Fahr., Oil Quenched, and No Draw Except as Noted.

When toughness is more important than either initial or secondary hardness, the lower hardening heats will generally give good results. The higher temperatures, that is, 2300 to 2400 degrees Fahr., must be used when maximum hardness is required. The range 2200 to 2300 degrees Fahr. seems to be a stable one.

From a hardness consideration only, high speed steel can be overdrawn. When the maximum drawing effect has occurred whether the time required has been thirty minutes or several hours, then a continuation of the draw will result in a gradual reduction in the hardness without a compensating increase in the deflection. If the draw is sufficiently prolonged the tool will not retain its file-hard condition. Impact tests may show increased toughness after severely prolonged draws in which event tools subject to shock could well be given a long draw. Deflection tests do

not indicate a marked increase in toughness after a greatly prolonged draw. If there is an increase in toughness, it may be associated with a slow change in the martensite. When drawing in salt, more time should be allowed than where lead is used. This applies only where short time drawing treatments have been the practice.

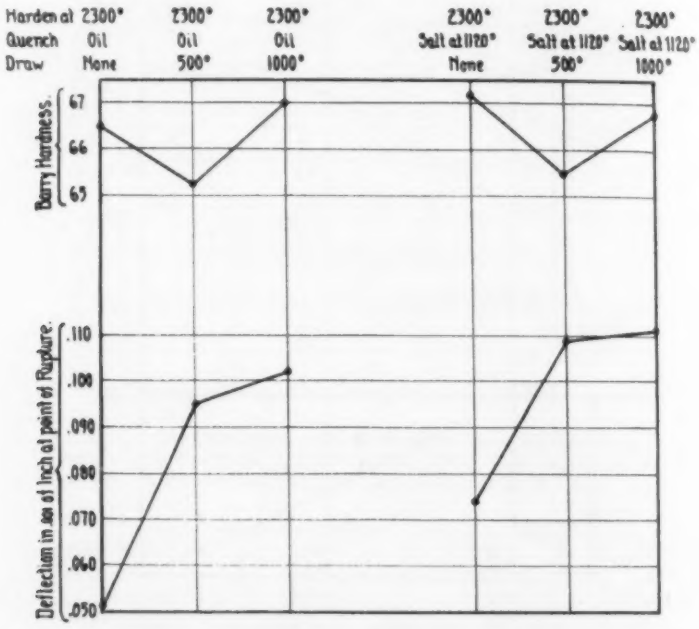

Fig. 6—Hardness and Deflection Curves Showing the Comparison Between an Oil and Salt Bath Quench from 2300 Degrees Fahr. and Drawn as Shown.

Fig. 5 shows the effect of time in the high heat at 2300 degrees Fahr., with an oil quench and no draw, except as noted.

Insufficient time at the high heat results in a lower initial hardness and a condition whereby subsequent drawing treatments will dangerously soften the steel. Excessive time at the high heat reduces the deflection causing brittleness but does not impair the hardness to a noticeable degree. In general a slight overtime is preferable to undertiming. The dotted line in Fig. 5 shows the effect of a high draw. Refer to the text under the heading "Precautions" for further comments on this matter of time.

Comparison between an oil and salt quench from a 2300-degree Fahr. high heat is shown in Fig. 6. The salt quench without a subsequent draw gave 0.023 inch more deflection than the oil quench, no draw. Salt-quenched steels should be drawn if

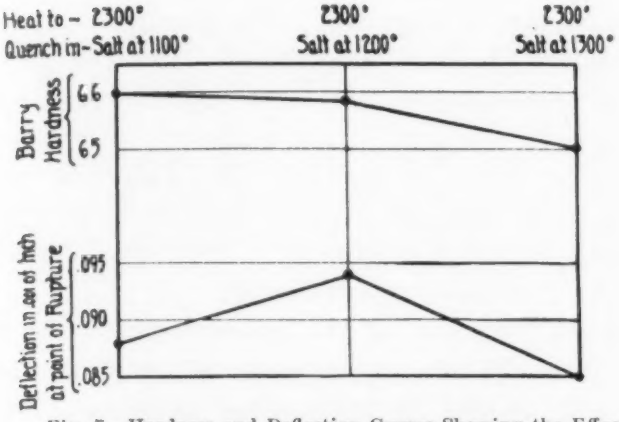

Fig. 7—Hardness and Deflection Curves Showing the Effect of the Temperature of the Salt Quenching Bath When Quenched from 2300 Degrees Fahr. No Drawing Treatment Used.

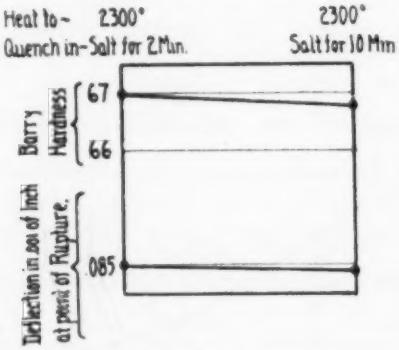

Fig. 8—Hardness and Deflection Curves Showing the Effect of Time Immersion in Salt Quenching Bath When Quenched from 2300 Degrees Fahr. No Draw.

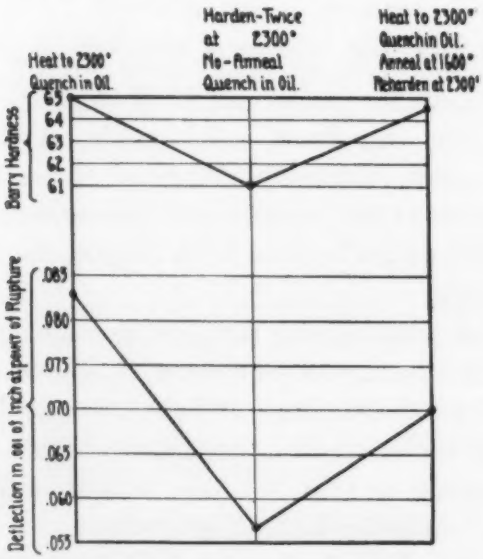

Fig. 9—Hardness and Deflection Curves Showing the Effect of Rehardening Without Annealing. 2300 Oil No Draw.

maximum toughness is required. The hardness values are quite similar for both methods of quenching. However, numerous tests have indicated that salt-quenched steels will average slightly harder than oil-quenched, when no draw is given. After drawing, the reverse condition seems to obtain. The deflection is higher for salt-quenched steels than for oil-quenched steels, each having been given the same drawing treatment. Prolonged draws might remove the slight differences encountered.

Fig. 7 shows the effect of the temperature of the salt-quenching bath, no draw. When quenching in salt with no draw contemplated, the bath should be maintained between 1150 and 1200 degrees Fahr. to obtain good hardness and fair toughness. Quenching into salt at 1300 degrees Fahr is not advisable under ordinary conditions, especially where the quench would be prolonged.

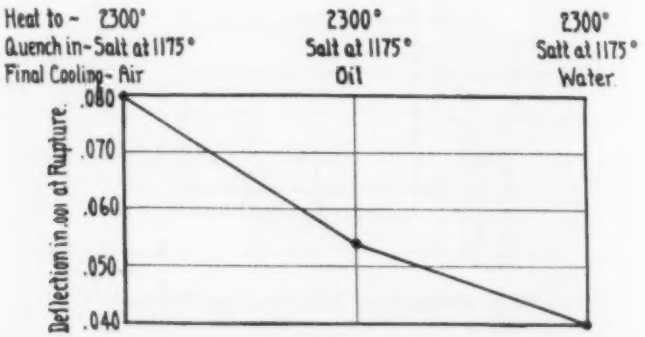

Fig. 10—Hardness Curve Showing the Effect of the Rate of Cooling from the Salt Quenching Bath.

Effect of time in the salt-quenching bath is shown in Fig. 8. The temperature of the bath was 1150 degrees Fahr., high heat 2300 degrees Fahr., no draw. When the steel being quenched had reached the color and temperature of the salt-quenching bath, it should be removed, for a prolonged immersion did not increase the deflection, and under certain bath conditions might tend to decrease the hardness.

The effect of rehardening without annealing, high heat 2300 degrees Fahr., oil-quench, and no draw is shown in Fig. 9.

The result of rehardening without an interhardening anneal reduces both the hardness and deflection. The effect of hardening persists, so much so that it seems almost impossible to restore the steel by any suitable annealing process. A hardness test is less sensitive than a deflection test in detecting an overheating.

Fig. 10 shows the effect of the rate of cooling from the salt-quenching bath to room temperature. The rate of cooling from the salt bath should not be too rapid, particularly when treating light pieces. The effect of water cooling after salt-quenching is given as a means of showing the close relation between low deflection and a highly accelerated final cooling.

It is assumed that the hardness value might be similar for all three methods.

Conclusions

The hardness and toughness of high speed steel may not be the best method of determining quality. Fortunately, however, the practical treater knows that certain reactions to definite tests parallel high tool efficiency.

No doubt, other methods of testing will be developed and accurate comparisons can then be made, but until then it might be well to adhere to hardness and toughness tests as a measure of the working ability of a given tool.

The writer wishes to thank the following for their interest and suggestions during the preparation of this paper: A. E. Bellis, J. P. Gill, A. H. d'Arcambal, J. K. Strauss, H. J. French and R. S. Archer.

Written Discussion: By M. A. Grossmann, United Alloy Steel Co., Canton, Ohio.

Many thousands of tests have shown that when high speed steel is broken in *impact*, it is more brittle after tempering at 1100 degrees Fahr. than after tempering at 900 degrees Fahr. According to recent tests at the Bureau of Standards, in which impact was compared with slow bend, the same trend was observed in the two kinds of test. That is to say, when comparing two materials in impact and in slow bend, the one which was more brittle in impact was also more brittle in slow bend. By analogy, high speed steel when tempered at 1100 degrees Fahr. should be more brittle under slow load than when tempered at 900 degrees Fahr. A well-known manufacturer of high speed tools has stated that this is the case, without however offering definite data.

The writer wishes to emphasize the fact that high speed steel is more brittle in impact when drawn at 1100 than when drawn at 900 degrees Fahr., and to point out that if this relation does not hold in slow load, then the difference in deformation must be explained.

Author's Reply to Discussion

An impact test shows steel hardened at 2230 degrees Fahr. is toughest when tempered at 880 degrees Fahr. If so, what does this mean in relation

to tool performance? Should we assume then that in order to meet certain conditions a cutting tool can be advantageously tempered to some medium degree, otherwise an impact test that indicates a low drawn specimen to be tougher than one tempered at 1100 degrees Fahr. has no practical value.

The high heat used and time at high heat have a direct bearing on the issue but need not be discussed at this time.

Should we conclude that mere softness or at least inferior secondary hardness means strength, if so, we must ignore the apparent contradictions accompaning low and very high draws as for example 600 and 1300 degrees Fahr. or higher.

A physical test interpreting only one kind of stress may be applied to practical problems when it is substantiated by actual work tests.

To conclude that a cutting tool will be strongest if tempered at 880 degrees Fahr. because impact test data so indicates, may be safe reasoning, if we are certain the stresses on the tool will be entirely dynamic, however the so-called dynamic stress can lose its distinctive nature so closely will it be merged with the static tensile compressive and torsional stresses which must be absorbed or resisted. Therefore it is possible for an impact test to indicate a certain treatment to be superior and then find that actual work tests do not substantiate the test data.

A tool tempered at 880 degrees Fahr. will be more severely stressed than one given the high draw because of the inferior hardness produced by low draws. The greater impact toughness of the low drawn tool is compensated for in this way.

In this connection it is significant that maximum general tool efficiency with the highest fiber stress tensile strength and deflection are developed by tempering temperatures considerably above 880 degrees Fahr.

When comparing the valve of impact tests with slow bend tests, several factors should be considered, namely, consistency, accuracy, sensitivity and verification.

The author of the paper under discussion has observed impact tests that were most inconsistent.

It would seem permissible to compute an average test value for any one treatment, provided the several tests from which the average had been obtained were reasonably close. However, when the test values varied as much as three hundred per cent for a single group of test pieces similarly treated we should hesitate to use such highly inconsistent results in determining an average value for the treatment under investigation.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON—PART III

By F. T. Sisco

Abstract

The present installment discusses the solidification of binary alloys whose component metals are insoluble in the molten state, resulting in the formation of eutectic alloys; and the solidification of binary alloys whose component metals are soluble in the solid state or solid solutions. The properties of eutectics and solid solutions are described and their structure illustrated.

OUR previous discussion was concerned with the determination of the temperatures at which constitutional changes occur in metals and alloys when they are cooled from the molten to atmospheric temperature and with plotting of these for a number of alloys of the same series, resulting in the equilibrium diagram. We have noted that the equilibrium diagram gives a graphic representation of the constitutional changes that occur in all of the alloys of the series.

The next step in our study of the constitution of steel and cast iron is to discuss the constitutional characteristics of two typical classes of alloys, the two classes that enter importantly into the constitution of the iron-carbon series. These two classes are eutectic alloys and solid solutions.

If we mix two molten metals we may have either of three conditions prevailing: the molten metals may be completely soluble in each other; they may be completely insoluble in each other;[24] or they may be partially soluble in each other.

[24]It is probable that a condition of complete insolubility does not exist in molten metals. Metals apparently insoluble at a temperature slightly above their melting point become appreciably soluble at higher temperatures. An example of this is aluminum and lead. At temperatures slightly above their melting points they separate into two distinct layers, like oil and water. As the temperature rises, the miscibility increases until the layers disappear. For practical purposes, however, we may say that some pairs of metals are insoluble in the molten state.

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In the solid state we may have the same three possibilities: two metals may be completely insoluble in each other; they may be completely soluble in each other, or they may be partially soluble in each other.

In addition to the above conditions prevailing in alloys of two metals, the metals may react with each other to form a chemical compound which in turn may be soluble, insoluble or partially soluble[25] in either or both metals.

To obtain a clear comprehension of the constitution of the iron-carbon series a study of two classes of binary alloys[26] is necessary; (1) Alloys completely soluble when molten and insoluble in the solid state. (2) Alloys completely soluble in both the molten and solid state.

The first results in the formation of eutectic alloys; alloys of the second class are known as solid solutions.

Solidification of Binary Alloys Whose Component Metals are Insoluble in the Solid State

As an example of binary alloys whose component metals are insoluble in the solid state we will consider the cadmium-bismuth series. The constitutional diagram for this series is shown in Fig. 9. In the previous discussion we constructed this diagram from the cooling curves of several alloys of bismuth and cadmium; in Fig. 9 the cooling curves have been omitted. The line ABC was drawn through the upper arrest points of the alloys and represents the liquidus or temperature where solidification begins; the line DBE was drawn through the lower arrest points of the alloys and represents the solidus or the temperature where solidification is complete. Let us follow the cooling of three alloys of bismuth-cadmium from the molten state to atmospheric temperature and note the constitutional changes taking place during cooling.

At 617 degrees Fahr. (325 degrees Cent.), point X, Fig. 9, an alloy containing 25 per cent bismuth and 75 per cent cadmium is wholly molten. This alloy cools unchanged to 509 degrees Fahr. (265 degrees Cent.), point X^1. Here an evolution of heat occurs

[25]For example, aluminum and copper combine to form the chemical compound $CuAl_2$. Copper is slightly soluble in aluminum. The solid solution of copper in aluminum forms a eutectic with the $CuAl_2$.

[26]A binary alloy is an alloy of two metals. Alloys of three metals are known as ternary alloys. The iron-carbon alloys are classed as binary alloys.

and solid cadmium starts to separate out of the melt. As the temperature drops from 509 degrees Fahr. (265 degrees Cent.) to 295 degrees Fahr. (146 degrees Cent.) more cadmium solidifies enriching the remaining liquid in bismuth until at the latter temperature, point X^3, the remaining liquid has a composition corresponding to point B on Fig. 9, or 61 per cent bismuth and

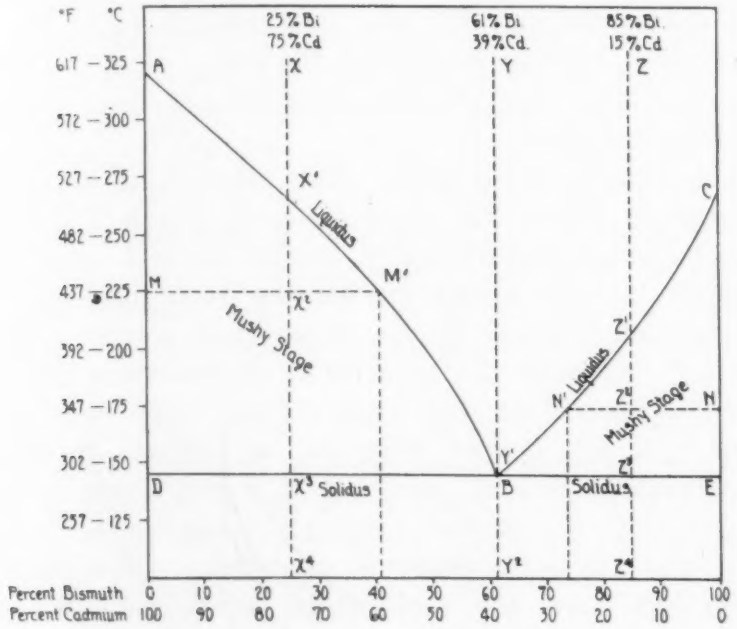

Fig. 9—Constitutional Diagram of Bismuth-Cadmium Alloys.

39 per cent cadmium. This is the eutectic alloy and solidifies at a constant temperature.

As the temperature drops from 509 degrees Fahr. (265 degrees Cent.), point X^1, to 295 degrees Fahr. (146 degrees Cent.), point X^3, the composition follows the curve AB; in other words, the amount of cadmium in the melt is decreased by the solidification of the pure metal and as it decreases the percentage of bismuth increases proportionally along the abscissae that intersect the line AB.

From Fig. 9 we can determine the ultimate composition of any alloy at any temperature. For example, at 617 degrees Fahr. (325 degrees Cent.) an alloy containing 25 per cent bismuth is wholly molten. When it has cooled to 437 degrees Fahr. (225 degrees Cent.), point X^2, we note from Fig. 9 that it is

partly solid and partly molten; it is in the mushy stage between the liquidus AB and the solidus DB. By drawing the abscissa MM^1 through the point X^2 we note that it intersects the liquidus at M^1 corresponding to 41 per cent bismuth. Hence at 437 degrees Fahr. (225 degrees Cent.) the alloy contains solid cadmium and molten metal containing 41 per cent bismuth and 59 per cent cadmium. At 295 degrees Fahr. (146 degrees Cent.) the abscissa drawn through X^3 will pass through point B. At 295 degrees Fahr. (146 degrees Cent.) the alloy consists of solid cadmium and molten metal[27] containing 61 per cent bismuth and 39 per cent cadmium.

What actually takes place when alloy X is cooled is this: at 617 degrees Fahr (325 degrees Cent.), point X, molten cadmium and molten bismuth are in solution in each other. At this temperature the two molten metals are in equilibrium. Let us consider molten bismuth as the solvent and molten cadmium as the solute.[28] At point X the solution is undersaturated.

Now as we cool to 509 degrees Fahr. (265 degrees Cent.), point X^1, the solution of cadmium in bismuth becomes more nearly saturated until at point X^1 it is exactly saturated. As soon as point X^1 is passed in cooling the solution becomes supersaturated and the equilibrium is disturbed. Consequently cadmium solidifies[29] and the equilibrium is restored. But as soon as this has occurred the alloy has cooled further and it is again supersaturated. Hence more cadmium solidifies. This continues until a temperature of 295 degrees Fahr. (146 degrees Cent.), point X^3, is reached. Here all of the excess cadmium has solidified and the remaining melt is of eutectic composition.

The eutectic is an alloy of definite composition and solidifies at a constant temperature, hence no more pure cadmium solidifies, instead the cadmium-bismuth eutectic freezes.[30]

Alloy Y containing 61 per cent bismuth (Fig. 9) is of eutectic composition, so it cools unchanged to 295 degrees Fahr. (146

[27]We are assuming that the temperature is just slightly above 295 degrees Fahr., which is the solidification point of the eutectic.

[28]Strictly speaking, this statement is not exactly true, but for purposes of discussion may be considered so.

[29]Carrying the analogy with our sugar and water example further, we might say it crystallizes out of solution.

[30]For a full discussion of the solidification of binary alloys based on the phase rule, the reader is referred to Hoyt, "Metallography-Principles," McGraw-Hill Book Company, Chapter I.

degrees Cent.), point Y^1, at which constant temperature the whole alloy solidifies. In this case the proportion of cadmium and bismuth are such that they are in equilibrium with each other at all temperatures.

In the case of the 85 per cent bismuth, 15 per cent cadmium alloy, Z, Fig. 9, we have a condition analogous to alloy X. At 617 degrees Fahr. (325 degrees Cent.), point Z, the alloy is wholly molten. It cools unchanged until 410 degrees Fahr. (210 degrees Cent.), point Z^1, where pure bismuth starts to solidify. As the temperature falls bismuth continues to solidify enriching the melt in cadmium. At 347 degrees Fahr. (175 degrees Cent.), point Z^2, the alloy consists of solid busmuth and molten metal of the composition measured by NN^1 or 74 per cent bismuth and 26 per cent cadmium. When the temperature has fallen to 295 degrees Fahr. (146 degrees Cent.), Z^3, all of the bismuth in excess of the eutectic ratio has solidified. At this temperature the eutectic becomes solid.

Below the solidus line DBE all of the alloys of bismuth-cadmium cool unchanged to atmospheric temperature. The solidification of the iron-carbon alloys takes place in much the same way as the alloys of bismuth-cadmium, but in addition have further changes taking place in the solid state.

Nature of Eutectic Alloys

The word eutectic is taken from the Greek, meaning "well melting". We have already noted that eutectic alloys behave very similarly to pure metals in that they have a definite freezing temperature. This freezing temperature is always below the freezing (melting) temperature of the metals making up the alloy.[31]

A characteristic of the eutectic that differentiates it from the chemical compound is that it contains its components in definite proportions which usually are not simple atomic or formula proportions.

Eutectics are nearly always fine-grained. When the eutectic is molten the atoms (or molecules) are in a state of high disper-

[31]The law of Raoult states that the addition of one molecule of B to A will lower its melting point by an amount which is independent of the nature of B. This law holds for dilute solutions and in case the solid phase which separates out is one of the pure components (Hoyt, Loc. Cit., page 18).

sion. When solidification occurs there is enough heat liberated to hold the temperature constant for a considerable time. This time is sufficient for the atoms (or molecules) to segregate into solid crystalline masses of like kind large enough to be seen distinctly by the microscope. There is not enough time available, however, for the masses to collect into large crystal aggregates as is usual in the slow, normal solidification of a pure metal.

In solidifying, the eutectic may assume a variety of forms. The most common form is shown in Fig. 10, the eutectic[32] alloy of bismuth and tin, in which the constituents are in the form of laminated plates, mostly in a parallel arrangement. The laminated structure suggests that the two constituents have different velocities of crystallization or that the particles of the phases crystallize alternately.[33]

Eutectics may also have a globular, or angular structure. Fig. 11, the binary eutectic of aluminum and the chemical compound Mg_2Si[34] shows the angular form encountered in aluminum alloys. In these alloys the angular eutectic may often be changed to the globular form by the addition of 0.02 per cent of sodium.[35]

In cast iron we encounter a eutectic which consists of austenite (a solid solution of carbon in gamma iron) and cementite (iron carbide Fe_3C). A representative structure is shown in Fig. 12.[36] We will discuss the formation of this eutectic in detail later.

The structure[37] of annealed steels of approximately 0.85 per cent carbon is shown in Fig. 13. The laminated structure is so nearly like a eutectic in appearance that this constituent in steels is known as the eutectoid. This constituent will also be discussed in detail in a later installment.

If we compare Fig. 12 with Fig. 10 the simple eutectic of bismuth-tin we find that both have the characteristic laminated appearance. Fig. 10 is a eutectic of two pure metals, while Fig. 12 is a eutectic of a solid solution and a chemical compound.

[32]Desch—Metallography, Longmans, Green & Co., 1913, Plate V, page 186.

[33]Desch—Loc. cit., page 185, also R. Vogel, Zeitsch., Anorg. Chem., 1912, Vol. 76, 425.

[34]Daniels—Properties of Some Sandcast Alloys of Aluminum-Magnesium Silicide, *Journal*, Industrial and Engineering Chemistry, In Press.

[35]Jeffries and Archer, Science of Metals, McGraw-Hill, 1924, page 345.

[36]Howe, Metallography of Steel and Cast Iron, McGraw-Hill, 1916, Plate III.

[37]From Metallurgical Files, McCook Field.

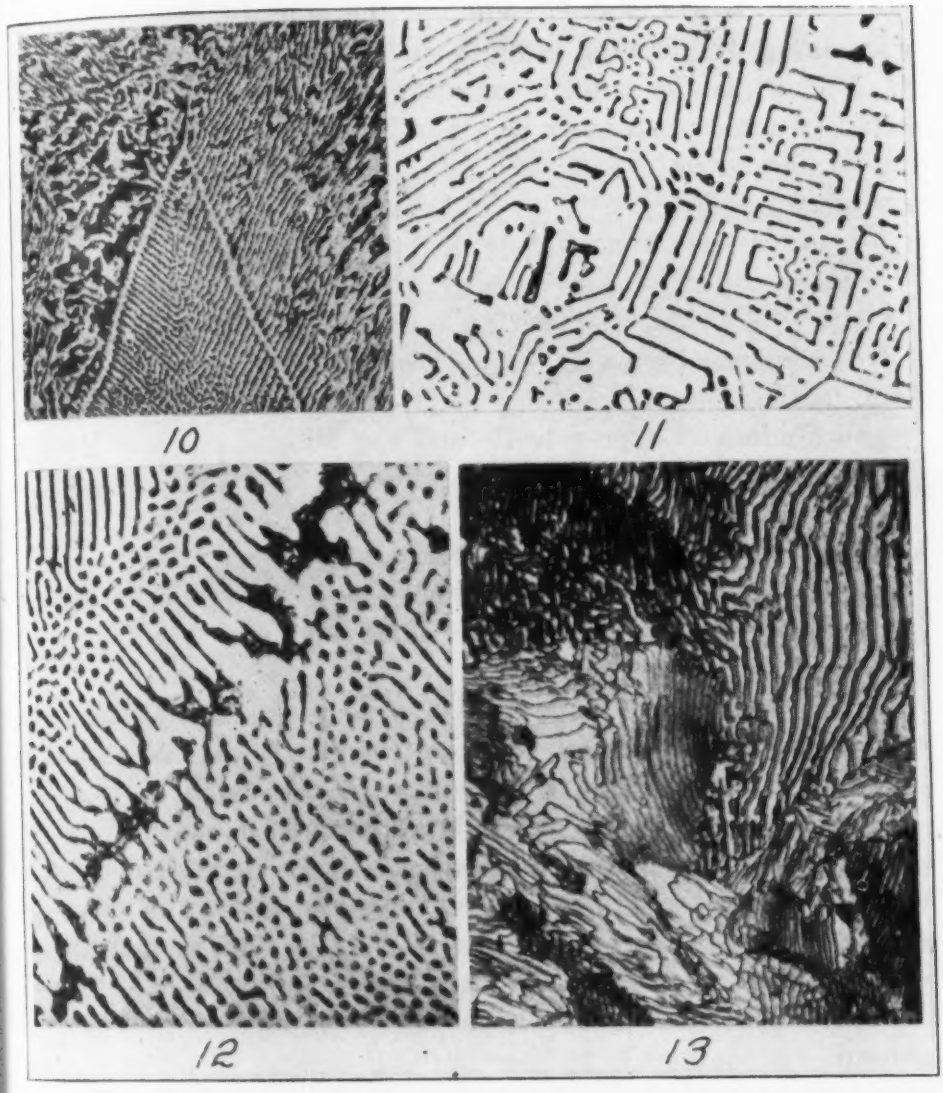

Fig. 10—Eutectic Alloy of Bismuth and Tin. . 200X. Fig. 11—Eutectic Alloy of Aluminum and Magnesium Silicide. Etched with 0.2 Per Cent Hydrofluoric Acid. 500X. Fig. 12—Eutectic Cast Iron. 180X. White Areas—Eutectic Cementite. Dark Areas—Eutectic Austenoid. Fig. 13—Eutectoid Pearlite. Carbon 0.85 Per Cent. Etched in Alcholic Nitric Acid. 1500X.

Fig. 11 is a eutectic of a pure metal and a chemical compound. Thus we see that a eutectic is an aggregate of two (or more) constituents, either or both of which may be a pure metal, a solid solution or a chemical compound.

Hypo-Eutectic and Hyper-Eutectic Alloys

In the case of a series of alloys of two metals insoluble in the solid state only one alloy of definite composition is the eutectic.

Referring to Fig. 9 it is seen that the alloy of bismuth-cadmium containing 61 per cent bismuth and 39 per cent cadmium (point B, Fig. 9) is the eutectic or alloy of lowest melting point. If an alloy contains more or less than 61 per cent bismuth it is made up of the eutectic and pure bismuth or cadmium. If the alloy contains less than 61 per cent bismuth it is known as *hypo-eutectic;* if more than 61 per cent it is *hyper-eutectic.* In other words, all alloys of a series lying to the left of the eutectic point on the equilibrium diagram are hypo-eutectic alloys and all that have reference points lying to the right are hyper-eutectic. In Fig. 9, the alloy X containing 25 per cent bismuth and 75 per cent cadmium is hypo-eutectic and the alloy Z containing 85 per cent bismuth is a hyper-eutectic alloy.

As we shall see later, cast irons with less than 4.30 per cent carbon are hypo-eutectic and with more carbon are hyper-eutectic. The same expression is used in steels:—With less than 0.85 per cent carbon the steel is hypo-eutectoid and with more than 0.85 per cent, hyper-eutectoid.

The structure of hypo- and hyper-eutectic alloys varies with the percentage of the excess constituent. When the proportion of excess constituent to eutectic is relatively small it may occur as a network or as small islands in a matrix of eutectic. When the percentage of excess constituent is relatively large, the conditions may be just reversed; in this instance the eutectic forms a network or rounded or angular particles in the matrix of the pure metal.

Fig. 14 shows three alloys of copper-silver.[38] Alloy B is the eutectic containing 28 per cent copper and 72 per cent silver.

Alloy A which contains 15 per cent copper is hypo-eutectic. The structure consists of a ground mass of eutectic containing large islands of silver, (with a little copper in solution). We might almost say that the ground mass was silver with a network of eutectic. Alloy C contains 65 per cent copper and is hyper-eutectic. In this case there is no doubt as to the relation between the eutectic and the excess constituent. The structure shows a sea of copper (with a little silver in solution) and reefs of eutectic.

The structural relationship between eutectic and the hypo-eutectic and hyper-eutectic alloys is very important. Much of

[38]Osmond—from Sauveur, Metallography and Heat Treatment of Iron and Steel, 1916—page 426.

our knowledge of the constitution of iron and steel is based on our ability to interpret the photomicrographs in terms of the equilibrium diagram.

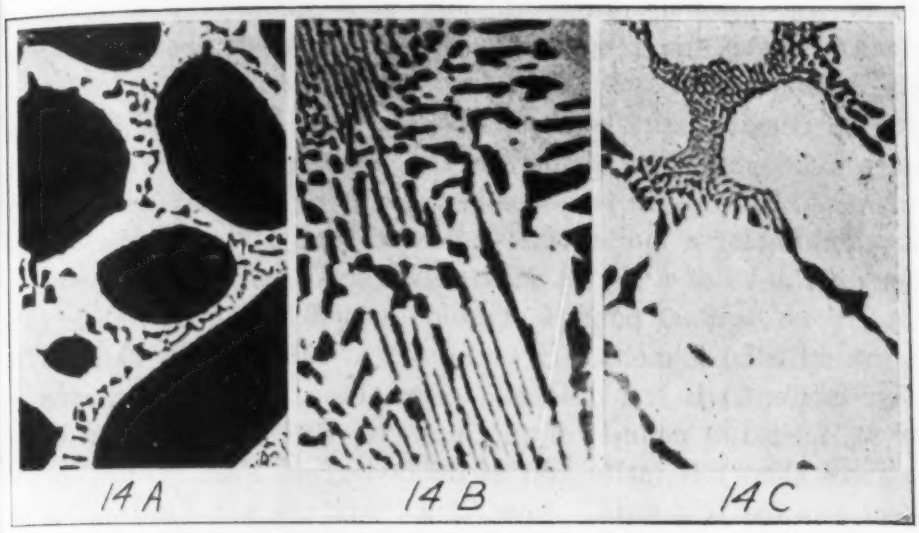

Fig. 14A—Hypoeutectic Copper-Silver Alloy. Copper 15 Per Cent. Dark Constituent is Silver (Containing a Small Amount of Copper in Solution). 600X. Fig. 14B—Eutectic Alloy of Copper-Silver. Copper 28 Per Cent. 600X. Fig. 14C—Hypereutectic Copper-Silver Alloy. Copper 65 Per Cent. Light Constituent is Copper (Containing a Small Amount of Silver in Solution). 600X.

The Solid Solution

Our discussion up to this point has been concerned with alloys of two metals soluble when molten, but insoluble in the solid state. This results in the formation of one eutectic alloy; the rest of the series are then hypo- or hyper-eutectic as the case may be. The eutectic alloy enters importantly into an understanding of the constitution of steel and cast iron. Another state common to alloys of two metals also enters prominently into the constitution of steel and cast iron and that is the solid solution. This is the result when two metals soluble in the molten state are also completely soluble when solid.

The concept of the solid solution is ofttimes a difficult one to visualize clearly. To the average person the term solution immediately brings to mind the picture of a liquid. That is because we are accustomed to correlating the term solution with such familiar things as sugar dissolved in coffee, salt dissolved in water and the like. Dissolving a solid in water is our most familiar type of solution. There is another type almost as familiar; a

liquid dissolved in a liquid. We know that when we add oil to water they separate into two distinct layers. The oil is insoluble in the water. When we add alcohol to water this does not happen. The alcohol is completely soluble in water in all proportions; the alcohol, unlike the oil, does not separate out into a distinct layer. It remains in solution at all temperatures below its boiling point.

In certain pairs of metals we have the same condition. The only difference is in temperature. Steel workers who become accustomed to think in terms of high temperatures have no difficulty in thinking of a molten metal in the same way that the average person thinks of a liquid such as water at ordinary temperature.

If we heat 50 pounds of gold to 1945.5 degrees Fahr. (1063 degrees Cent.) it melts. If we heat it to 2500 degrees Fahr. (1370 degrees Cent.) it is a fluid and resembles a fluid in its properties. If we heat 100 pounds of platinum to 3191 degrees Fahr. (1755 degrees Cent.) it melts and at 3500 degrees Fahr. (1930 degrees Cent.) it too is a fluid. Now, if we mix the two fluid metals we have a solution of gold in platinum. Let us think of the platinum as water and the gold as alcohol. For the present we may consider that the only difference between a solution of 50 pounds of molten gold in 100 pounds of molten platinum and a solution of a quart of alcohol in two quarts of water is one of temperature. They are both solutions. In other words, the atoms of gold are highly and uniformly dispersed in the fluid platinum just as the alcohol is in molecular dispersion in the fluid water.

If we allow the solution of 50 pounds of gold in 100 pounds of platinum to cool undisturbed, when it reaches 1900 degrees Fahr. (1040 degrees Cent.) it is all solid, but it is still a solution. The gold has not separated out from the platinum like oil from water, it is still in solution in the platinum, although the two metals are both solid. The atoms of gold are highly and uniformly dispersed in the platinum[39] and we have a *solid solution.*

A solid solution is a condition whereby two substances retain in the solid state all of the characteristics held by them when in solution in the fluid state.

Many pairs of metals are soluble in each other in the solid state. Among them are iron-cobalt; iron-nickel; iron-manganese;

[39]This is not strictly true but we may for the moment omit the slight heterogeneity that is the result of solidification.

nickel-chromium; nickel-manganese; cobalt-chromium; gold-platinum; silver-gold; tungsten-molybdenum and many others.[40] A large number are partially soluble in the solid state. This gives rise to a condition whereby both a solid solution and a eutectic may possibly be present in the same alloy.

One of the most common examples of a solid solution is glass.[41] In this solid, the silica, lime and alkali are completely merged in indefinite proportions. A number of slags, especially the hard glasslike vitreous slags from the acid open-hearth process are or contain solid solutions.

A solid solution may be either crystalline or amorphous—

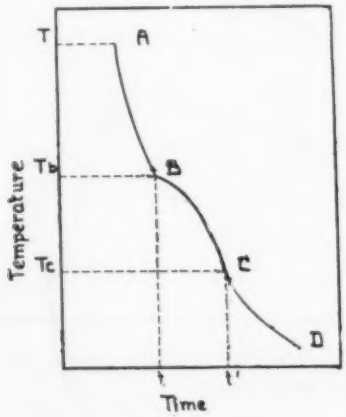

Fig. 15 — Cooling Curve of Two Metals Soluble in the Solid State.

in metals it is usually crystalline—a solid solution may consist of two or more pure metals; it may consist of a pure metal and a chemical compound; it may consist of a pure metal and a eutectic alloy; or an alloy and a chemical compound.

In steel the solid solution which we will consider is a solution of carbon or iron-carbide in iron. If we accept the first concept our solid solution is of a metal and non-metal, if the latter is true our solution is the metal iron and the chemical compound iron-carbide, Fe_3C.

Solidification of Solid Solutions

It will be observed that in the cooling curve of an alloy of two metals soluble in each other, two arrests will be noted, one

[40] See Jeffries and Archer—Science of Metals, McGraw-Hill, 1924, Table XVII, page 268.

[41] It is customary to consider glass a solid solution, although in reality it is a liquid solution; an undercooled fluid of high viscosity.

at the beginning and one at the end of solidification. A typical curve is shown in Fig. 15.[42] The beginning of solidification B and the end of solidification C are marked by a change in the direction of the curve rather than a distinct arrest and not—as in the case of two metals insoluble in the solid state—by a distinct break

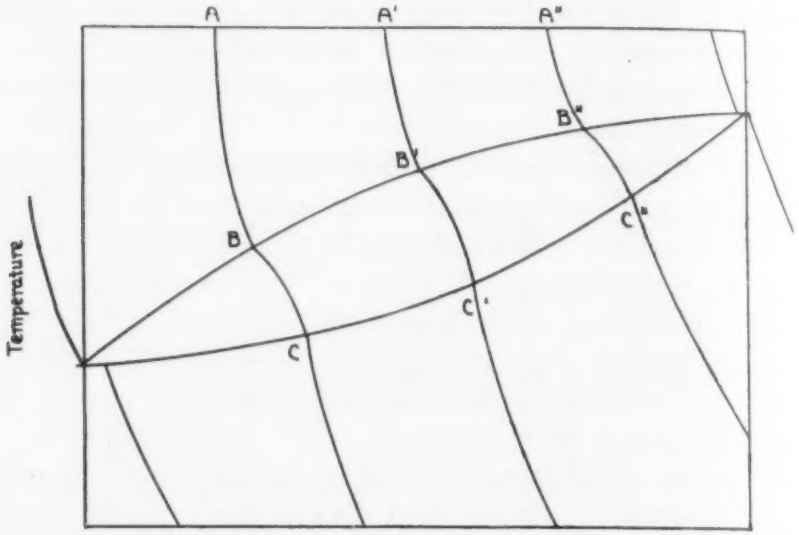

Fig. 16—Constitutional Diagram of Two Metals Soluble in Each Other in the Solid State.

in the curve at the temperature where the eutectic freezes. In the latter case there will be a horizontal jog at the point C the length of which is dependent upon the amount of eutectic solidifying at this constant temperature.

Fig. 16 is a skeleton[43] equilibrium diagram of a series of alloys whose two components are soluble in each other in the solid state. At each end of the diagram is the pure metal with only one arrest in the cooling curve where solidification takes place at constant temperature. All of the other alloys have two breaks in the curve, one at B the beginning of solidification and one at C the end of solidification.

Fig. 17 shows the diagram for the alloys of gold and platinum. The upper line, ACB, is the liquidus, the lower, AC'B, is the solidus. It will be noted that alloys of two metals which form solid solutions have a mushy stage of variable extent, usu-

[42]Sauveur—Heat Treatment and Metallography of Iron and Steel, page 411.

[43]Sauveur—Loc. Cit., page 413.

ally ranging from nil for a pure metal to the maximum near the center of the diagram.[44]

To understand the solidification of alloys whose components are soluble in each other in the solid state we will trace the solidification of an alloy containing 50 per cent gold and 50 per cent platinum, X, Fig. 17.

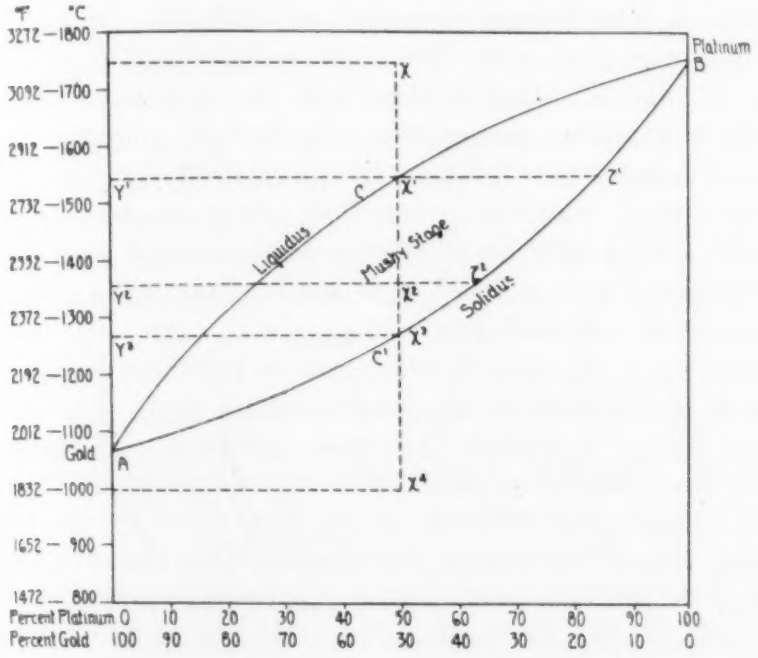

Fig. 17—Constitutional Diagram of the Platinum-Gold Alloys.

At 3182 degrees Fahr. (1750 degrees Cent.), point X, the alloy is wholly molten and consists of a solution of molten gold in molten platinum (or vise versa). The alloy cools unchanged until 2822 degrees Fahr. (1550 degrees Cent.), point X^1, is reached. At this point solidification starts by the deposition of solid solution.

Referring back for a monment to alloy X in Fig. 9 containing 25 per cent bismuth and 75 per cent cadmium, these two metals are insoluble in each other when solid, hence solidification begins by the deposition of pure cadmium. The solidification of the pure metal continues as the temperature falls until the remaining melt is of eutectic composition.

[44] This is true for alloys of this type. In another type in which the freezing point passes through a minimum the mushy state is nil near the center of the diagram. See Hoyt, "Metallography, Principles," McGraw-Hill, 1920, pages 16, 17.

Turning again to Fig. 17, we have noted that at X^1 solidification begins by the deposition of a solid solution of gold and platinum, and not by the deposition of a pure metal. As the temperature falls from 2822 degrees Fahr (1550 degrees Cent.) to 2300 degrees Fahr. (1260 degrees Cent.) more solid solution freezes out until at X^3 the alloy is wholly solid. Cooling is then unchanged to atmospheric temperature.

Let us consider this process more in detail. In the first place pure platinum freezes at 3191 degrees Fahr. (1755 degrees Cent.) point B, Fig. 17. It is evident that the addition of molten gold to molten platinum lowers the solidification point along the line ACB. The solid solution that freezes at 2822 degrees Fahr. (1550 degrees Cent.) contains a relatively large amount of platinum. It is not a solid solution of 50 per cent gold and 50 per cent platinum; instead it is a solution of approximately 85 per cent platinum and 15 per cent gold.[45]

As soon as the solid solution rich in platinum begins to freeze, the melt is enriched in the lower-melting gold. The equilibrium is immediately disturbed and more platinum-rich solid solution freezes, this time of a lower percentage of platinum than before. As the temperature falls along the line of X^1X^3, the solid solution that freezes out will at any moment have the composition represented by the intersection with the solidus AC^1B, of a horizontal coordinate drawn through that temperature. For example, when the alloy has cooled to 2462 degrees Fahr. (1350 degrees Cent.), point X^2, the solid solution which freezes at this point has a platinum content of approximately 65 per cent. At X^3 solidification is completed by the solidification of a solid solution containing 50 per cent platinum. As the percentage of platinum in the freezing solid solution decreases along the solidus line AC^1B the melt is enriched in gold along the liquidus line ACB.

From the above discussion we would be led readily to the assumption that the solid alloy of platinum and gold is extremely heterogeneous, being made up of minute crystals of widely varying compositions. This would be true were it not for diffusion. It is well known that liquid solutions tend to become homogeneous by diffusion which takes place rapidly. Diffusion also takes place in the solid state but less rapidly although in the case of a normally

[45]The amount is found by extending the horizontal coordinate Y^1X^1 to the right until it intersects the solidus ACB at Z^1.

cooled alloy of sufficient mass it may be considered practically complete.

In the case of the platinum-gold alloy, the platinum will tend to diffuse from platinum-rich crystals into the platinum-poor crystals thus resulting in a more or less homogeneous solid. In this connection it must be remembered that crystallization begins at a large number of centers, consequently it may only be necessary for an element to diffuse over a distance of 0.00003937 inch or less. We will discuss diffusion more in detail when we take up the solidification of the iron-carbon alloys. It is well to remember in this connection that diffusion starts simultaneously with solidification, hence the deposition of crystals at point X^1, having the composition Z^1, is only a theoretical conception of equilibrium conditions at this point.

The mushy stage may be relatively great as in the gold-platinum alloys represented in Fig. 17 or it may be of short duration as in the copper-manganese or copper-nickel alloys.[46]

Structure of Solid Solutions

The structure of solid solutions may vary widely. If an alloy contains a single solid solution it crystallizes in much the same way as a pure metal with polyhedral grains evident upon etching. Fig. 18 is an example[47] of the structure of a homogeneous single solid solution of copper-zinc. Fig. 19, very similar to Fig. 18 in appearance, is austenitic manganese steel containing 10 per cent manganese.

When the alloy is composed of two solid solutions as is the case with many of our brasses the structure will show crystals of one constituent surrounded by the other. Fig. 20,[48] the structure of a brass containing 60 per cent copper and 40 per cent zinc, shows the alpha and beta solid solutions, and Fig. 21 the alpha, beta solutions in aluminum-bronze.

In many solid solutions the structure resembles that of an alloy whose metals are insoluble when solid (eutectic); crystals of one of the solid solutions will surround the other as a network, or occasionally islands of one solution will be found in the ground

[46]Desch—Metallography, pages 50 and 51.

[47]Sauveur, Loc. Cit., page 412.

[48]Guillet and Portevin, Metallography and Macrography, Bell, 1922, page 218, Plate 76.

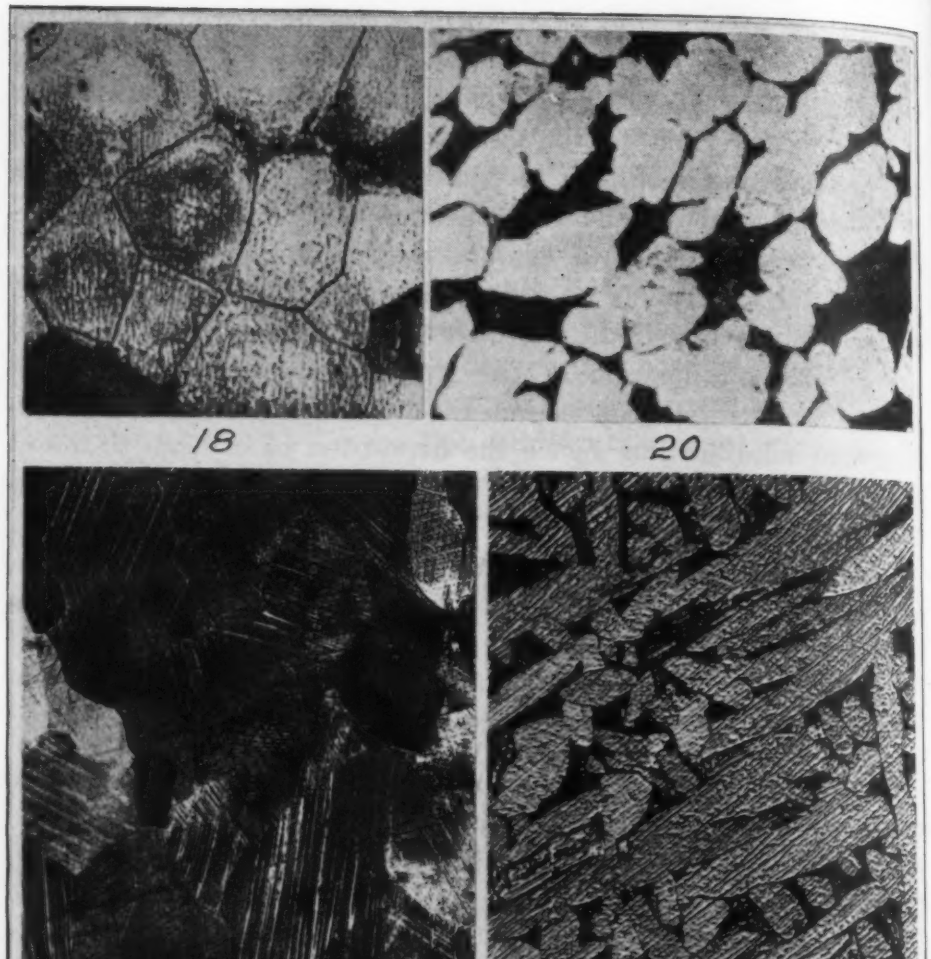

Fig. 18—Copper-Zinc Alloy. 50 Per Cent Copper. 200X. Homogeneous Solid Solution. Fig. 19—Solid Solution. Manganese Steel, Austenite. 100X. Etched in 2 Per Cent Alcoholic Nitric Acid. Fig. 20—Brass. Solid Solution of Alpha Plus Beta Brass. 100X. Etched with Acid Ferric Chloride. Fig. 21—Aluminum Bronze. Solid Solution of Aluminum and Copper. Etched with Ferric Chloride. 500X.

mass of the other solution. A solid solution may usually be distinguished from a eutectic alloy by the absence of the characteristic angular or laminated form which the eutectic usually takes.

If an alloy made up of one or more solid solutions is cooled fairly rapidly the crystals will be heterogeneous in composition. For example, in a copper-zinc alloy containing 20 per cent zinc

the zinc content in the center of the grain will be low, the percentage of zinc then increases from center to boundary of grain. In addition, different grains may vary somewhat in composition. By heating such an alloy to a temperature somewhat below the solidus line, in this case about 1500 degrees Fahr. and holding for a sufficient time, diffusion will take place resulting in complete homogeneity.

In such alloys as brass a homogeneous structure results from hot or cold working followed by annealing.

Types of Solid Solutions

The knowledge of crystal structure gained by X-ray methods has given us a new conception of solid solutions. This has been discussed fully elsewhere[49] so only a brief survey is advisable here. Until these X-ray studies were made the solid solution was considered as a complete merging of the two metals in indeterminate proportions. Or to quote Professor Howes' words,[50] "..... Many of our metals, as it were, dissolve in each other, and we find them in the solidified state completely merged in each other, forming alloys which differ from specimen to specimen by infinitesimal gradation, and yet the component metals cannot be distinguished in the alloy by the microscope or by any other means. The separate individual existence of each has ceased. Here we have the essential characteristics of solutions, viz, (1) complete merging of the components, (2) in the indeterminate proportions; and on this account we give to these substances the name of solid solutions."

Let us now consider two typical solid solutions of binary alloys in the light of their atomic arrangement. First we will take the alloys of copper and nickel, soluble in each other in all proportions. Both elements crystallize as a face-centered cube. The dimensions of the lattice are almost the same. All of the alloys will have the same structural appearance under the microscope. The X-ray tells us that all of the alloys are a face-centered cube. It follows that these alloys are true solid solutions. The two metals are completely merged, they are mutually soluble in each other, there is only one solid solution.

[49] See Jeffries and Archer—"Science of Metals," McGraw-Hill, 1924, page 236, et seq.

[50] Howe—Iron, Steel and Other Alloys, McGraw-Hill, 1906, page 10.

Now consider the alloys of nickel and chromium. These have always been considered as mutually soluble in all proportions. Nickel crystallizes as a face-centered cube and chromium as a body-centered cube. X-ray analysis of the alloys shows that up to about 65 per cent chromium the structure is a face-centered cube.[51] From this we take it that from 0 to 65 per cent chromium is soluble in nickel; the chromium atoms are occupying positions of some of the nickel atoms in the face-centered lattice. When the percentage of chromium is between 65 and 93, two types of lattice are present, the face-centered cube of the nickel, and the body-centered cube of the chromium. With more than 93 per cent chromium the structure is the body-centered lattice of chromium.

This tells us that in the alloys of nickel-chromium we have three structural conditions possible; (1) a solid solution of chromium in nickel, (2) a solid solution of nickel in chromium and (3) a mixture of the two solid solutions.

Solid solubility of one component in another frequently varies with the temperature. For example, at 1886 degrees Fahr. (1130 degrees Cent.) 1.70 per cent of iron carbide is soluble in iron; at 1335 degrees Fahr. (725 degrees Cent.) only 0.85 per cent is soluble and at atmospheric temperature less than 0.10 per cent is soluble.

[51] Jeffries and Archer, Loc. Cit., page 238.

Editor's Note: The next installment will take up the constitution of the low and medium carbon steels.

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part VIII

By H. B. Knowlton

Abstract

This article covers the manufacture, properties and uses of the plain carbon steels other than tool steels from the standpoint of the consumer. The processes of manufacture are touched on briefly in order to explain the properties of steels made by the different processes. The effect of the different carbon contents upon the properties of steel is described, and numerous examples are given of the uses of the different grades and classes of steel.

Low and Medium Carbon Steels

High Carbon Steels Other than Tool Steels

THE previous articles have dealt with the composition, properties, uses and methods of heat treatment of the tool steels. Although these steels are of vital importance to the heat treater, they constitute only a small portion of all of the steel produced. Less than 0.1 per cent of the annual tonnage production of steel is tool steel. Most of the balance falls in the low and medium carbon classes. Of course, a considerable portion of these steels are not particularly interesting to the heat treater because they do not receive any heat treatment in the plant of the consumer. On the other hand many tons of low and medium carbon steels, with and without other alloying elements, are heat treated every year, and the heat treatment of these steels seems to be becoming more and more important.

Before taking up the discussion of the heat treatment of the medium carbon steels, it may be well to give a brief description of the steels which fall in these classes. For the sake of simplicity, the plain carbon steels will be discussed first. These steels may be classified in two ways: according to the methods of manufacture, and according to the carbon content.

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions, the second installment appeared in the June, 1925, issue, the third installment appeared in the October, 1925, issue, the fourth installment appeared in the January, 1926, issue, the fifth installment appeared in the April, 1926, issue, the sixth installment appeared in the May, 1926, issue, and the seventh installment appeared in the June, 1926, issue

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Classification According to the Methods of Manufacture

There are seven common methods for the manufacture of steel: (1) the acid Bessemer, (2) the basic Bessemer, (3) the acid open-hearth, (4) the basic open-hearth, (5) the acid electric, (6) the basic electric, (7) the crucible. To these may be added the blister method, but as this method is not much used as a final operation in the production of steel, it may be eliminated from the present discussion. The following paragraphs will deal only with the general properties of steels produced by the different methods. The manufacture of steel is too large a subject to be discussed in detail herein. There are a number of good books on this subject. The reader of Transactions is especially referred to the articles by Sisco[1] and to the text books by Stoughton[2] and Camp and Francis[3].

Acid and Basic Steels

When pig iron and steel scrap are to be refined into steel, they are melted and the impurities are burned out. The carbon in the pig iron burns to form a gas which naturally bubbles up through the melted metal and passes off, but the other impurities either remain in the steel or else form a slag which floats to the top. Fluxes may be added which aid in cleaning the steel and retaining the impurities in the slag. The composition of the steel produced depends somewhat upon the slag. The lining of the furnace must agree chemically with the slag.

Slags may be divided into two classes, acid and basic. In the acid slag the flux is silica while in the basic it is lime. Basic slags will remove phosphorus and partially remove sulphur from the steel, while the acid slags do not remove these objectionable impurities. On the other hand Sisco states that with an acid slag it is easier to deoxidize the steel and to remove dirt and gas. As the acid process does not remove sulphur and phosphorus it is necessary to start with pig iron and steel scrap which are low in these impurities. It should be added that good or poor steel may be made either method depending upon the skill of the melter.

[1]Manufacture of Iron and Steel, by F. T. Sisco, Transactions of American Society for Steel Treating, August and September, 1925.

[2]Metallurgy of Iron and Steel. Bradley Stoughton.

[3]Making, Shaping and Treating of Steel. Camp and Francis.

Acid Bessemer Steel

Bessemer steels in this country are made in acid-lined furnaces. The process consists of blowing air through melted pig iron, thus burning out the carbon, manganese and silicon, and finally adding recarburizers which quiet the metal and bring the carbon and manganese content to the desired proportions. The method is cheap and rapid. It requires only about 15 minutes to convert 15 tons of pig iron into steel. No fuel is required. Sulphur and phosphorus, both of which make steel brittle, are not removed by this method. The phosphorus content of the finished steel made in the Bessemer converter usually runs from about 0.07 per cent up. The S. A. E. specification for Bessemer screw stock allows a phosphorus content of 0.09-0.13 per cent. Other Bessemer steels usually contain less than 0.10 per cent phosphorus. Open-hearth steels are frequently purchased on a specification of 0.045 per cent maximum for phosphorus. The sulphur content may be high or low depending upon the iron used in making the steel. There is also much greater danger that Bessemer steels will contain excessive amounts of oxides, slag, and non-metallic inclusions, than there is with the steels made by other methods.

Bessemer steels are satisfactory for parts which do not have to meet drastic requirements in service. They may even have an advantage for some kinds of pipe, for screw machine products and for other parts, for which easy machining is of maximum importance, and strength is not required. They may be used for sheet metal parts which are not severely cold-worked in manufacture and which do not stand heavy loads in service. Sisco states that the use of Bessemer steel for structural shapes, rails and plates has been practically discontinued. The A. S. T. M. specifications for 1924 allows the use of either Bessemer or open-hearth steels for structural shapes for buildings, for reenforcing rods for concrete construction, for low and medium carbon rails, but demands open-hearth steels for bridge construction, for high carbon rails and for many other parts which meet drastic service conditions. Bessemer steels are decidedly not recommended for parts which are to be case hardened, or given any heat treatment involving quenching. The following pages explain some of the uses for which steels made by the different methods are recommended.

Basic Bessemer Steels

The basic Bessemer method is important in Europe but is not used in this country as it is not adapted to the American ores. The steel produced by this method is superior to our acid Bessemer steels, as the method does remove phosphorus. By the use of this method it has been possible for certain countries to utilize large ore deposits which were once considered worthless on account of the high phosphorus content.

Basic Open-Hearth Steels

The basic open-hearth method is decidedly the largest steel producer in the United States, turning out approximately 75 per cent of our annual tonnage. Low, medium, and even some fairly high carbon steels both with and without alloys are made by this method. Only the high grade tool steels and some of the special high quality alloy steels are beyond the scope of the open-hearth furnace method.

This process is much slower than the Bessemer, requiring from 6 to 12 hours, but the quantity tapped at one time is usually larger. 100-ton heats are not uncommon. There is opportunity to make tests of the metal, to make additions to control the composition of the slag and the metal. It is even possible to make a chemical analysis of the metal before tapping and to make the final additions on the basis of this information.

The basic open-hearth steels are as a rule cleaner and freer from impurities than Bessemer steels. The content of sulphur and phosphorus may be held below 0.05 per cent for each. These steels are suitable for parts which must withstand either stationary or moving loads. They will stand heat treatments involving quenching, without the danger of cracking that is frequently encountered when it is attempted to quench Bessemer steels. Of course, if the steel contains seams, pipes, or other flaws, it may crack regardless of which method was used in its production. The strength and toughness of open-hearth steels will vary with the chemical composition, and the methods of casting, forging and heat treating.

Acid Open-Hearth Steels

The acid open-hearth process is similar to the basic except that an acid lining and an acid slag are employed. This necessi-

tates certain changes in the details of the process. While sulphur and phosphorus cannot be removed by this method, the acid slags have some advantages in the production of clean sound steel. As the raw materials used must be lower in sulphur and phosphorus than those used in the basic open-hearth method, the cost may be higher. Sisco states that in spite of the fact that the sulphur and phosphorus in finished acid open-hearth steel is higher than that in the basic steel, most metallurgists will agree that the acid steel is superior on account of its greater freedom from dirt, slag and gas inclusions. He points out that the acid open-hearth steels have proved satisfactory for heavy ordnance and armor plate while the basic open-hearth steels have not.

Acid Electric Steels

The electric furnace processes are similar to the open-hearth except that an electric arc is used for heating. The acid electric process is quite popular in the manufacture of steel castings. It is possible by this method to make a relatively clean, sound steel. However it should be stated that the mere fact that an electric furnace is employed, is no assurance that the steel produced will be of superior quality. The writer has inspected a great many electric steel castings which were not as clean as the best castings produced by other methods. This is no criticism of the method, however. The electric furnace is a fine tool. It is particularly advantageous in small installations. Furnaces of 3-ton capacity are quite common in foundries and furnaces as small as ¼-ton capacity have been used for some purposes. Open-hearth furnaces usually run from about 15 tons up. While both acid and basic electric furnaces have been used in steel founding, the acid furnaces are probably the more common. They are usually considered easier to handle.

Basic Electric Steels

It is possible with the basic electric furnace to produce a cleaner grade of steel than can be produced by any other method except the crucible. The high temperature of the electric arc produces a very hot slag. It is possible, therefore, to add a large amount of lime, making a very basic slag which almost completely removes the sulphur. With the help of carbon added to the same slag the metal is quite thoroughly deoxidized. It is customary

to employ two or more slags in a basic electric heat. The first slag is used to oxidize and remove almost the last traces of phosphorus. The electric furnace has an additional advantage over the fuel-heated open-hearth furnaces in that there are no objectionable gases present in the furnace to hinder the refining of the steel.

The basic electric method is more expensive than the open-hearth. It is used in the production of the highest grades of steel of all chemical compositions. A high grade of low carbon alloy steel for case hardened roller bearings has been produced by this method. Even high grade tool steels are made in the basic electric furnace. The discussion as to whether these are equal, superior or inferior to the crucible tool steels, will not be taken up in this article.

Combined Methods

The combining of two or more of these methods, such as the Bessemer and the open-hearth, the open-hearth and the electric, or the combination of all three should need no discussion here. These are important to the manufacturer from a cost standpoint, but for the benefit of the user who is interested in learning the quality of the steel as he receives it, suffice it to say that the quality should depend upon the final method employed, not upon the first or intermediate stages of refining.

Rating of Different Methods

Sisco gives the following rating of the different steel-making methods with respect to the quality of steel produced. (1) crucible, (2) basic electric, (3) acid electric, (4) acid open-hearth, (5) basic open-hearth, (6) acid Bessemer. It may be well to repeat the caution that a great deal depends upon the skill of the melter and that it cannot always be assumed that a steel is particularly high grade because a high grade method is employed. The above rating shows rather the comparative ability of the different methods to produce sound steel providing they are carried out properly.

Classification of Steel According to the Carbon Content

Plain carbon and low alloy steels may also be classified according to their carbon content. Thus steels are sometimes divided into three general classes: low carbon, medium carbon, and high

carbon. Low carbon steel is sometimes called soft, or mild steel, while the medium carbon steels have been called half-hard steels.

It is difficult to draw any sharp dividing lines between these classes. It may be said in a general way that the low carbon steels contain from almost 0.00 per cent carbon to about 0.25 per cent carbon; the medium carbon steels from about 0.25 per cent carbon to about 0.70 per cent carbon; and the high carbon from about 0.70 per cent to about 1.50 per cent carbon. These may be further divided by calling the steels containing below 0.10 per cent carbon very low carbon, and the steels containing more than 1.20 per cent carbon, very high carbon. The present writer would prefer dividing the medium carbon steels into two classes, calling those containing 0.25-0.55 per cent carbon and those containing 0.55-0.75 per cent carbon medium high carbon, as there is some difference in the uses of these two classes of steel.

The use of the terms low, medium, and high carbon will vary somewhat depending upon the place they are used. Thus in a steel foundry a 0.50 per cent carbon steel may be called "high carbon" while in a tool steel mill a 0.70 per cent carbon might be termed "low" and so on.

As a matter of fact none of these terms are definite enough to describe any one steel. It is customary to hold the carbon content of any one particular steel within a variation of about 0.10 per cent (plus or minus 5 points) from the desired composition. Sometimes much closer limits are required.

Effect of Carbon Content on Plain Carbon Steels

A pure iron with 0.00 per cent carbon would be a soft, tough, ductile material. It would have a lower tensile strength than any steel containing carbon. It could be forged either hot or cold and could be welded easily. It would be fairly resistant to rusting and corrosion. It would have no ability to harden if heated and quenched. It would have a tensile strength of about 50,000 pounds per square inch and an elongation in 2 inches of about 40 per cent.[4]

If even a small amount of carbon is alloyed with the iron, the tensile strength would be slightly increased, the elongation (and the toughness) would be very slightly decreased, the ability to stand forging and welding would theoretically be decreased, and

[4]Metallography and Heat Treatment of Iron and Steel. Albert Sauveur.

the resistance to rust and corrosion would be decreased. If the carbon content is extremely low these effects will be small. The hardening power of a very low carbon steel is so slight as to be almost unmeasurable.

As the carbon content is increased from nearly zero to about 0.85 per cent, the following changes in the physical properties of annealed steel may be noted:

The tensile strength increases from about 50,000 pounds to about 125,000 pounds per square inch.

The elongation decreases from about 40 per cent to about 10 per cent.

The forgeability and weldability decrease.

The hardening power increases.

The effect of strengthening and toughening heat treatments increases.

It is sometimes stated that steels containing less than 0.25 per cent carbon cannot be hardened. It might be better stated that the hardening power of such steels is so slight that it is of no practical value.

Properties and Uses of Steels of Varying Carbon Contents

0.00-0.05 Per Cent Carbon. Steels are seldom made as low as this in carbon. Wrought iron and ingot iron fall in this class. They are very tough and will stand a great deal of forging either cold or hot. They are easily welded and on account of their purity they are fairly resistant to rust and corrosion.

0.04-0.10 Per Cent Carbon. *Very low carbon steels* Open-hearth steels in this class forge quite well either cold or hot but probably not equal to wrought iron. Rivet steel is one example of this class. The A. S. T. M. specification for rivet steel calls for acid or basic open-hearth with sulphur not over 0.045 per cent and phosphorus not over 0.06 for acid steel or 0.04 for basic.

0.05-0.25 Per Cent Carbon. *Low carbon steels* These steels may be subdivided into numerous classes. Some of them are bought on physical tests without definite limits for carbon content. Only a few examples will be given.

Structural steel for bridges, cars, locomotives, and ships A. S. T. M. specifications require open-hearth steel and limit the sulphur and phosphorus content. Tensile strength requirements vary from 50,000-60,000 to 58,000-68,000 pounds per square inch.

Structural steel for buildings A. S. T. M. specifications allow either Bessemer or open-hearth. Phosphorus limits 0.10 per cent for Bessemer, and 0.06 per cent for open-hearth. Tensile strength 55,000-65,000 pounds per square inch.

Billet blooms and slabs for forgings The A. S. T. M. specifications cover several grades of steel with carbon contents from 0.05-0.60 per cent, with and without alloys. Open-hearth or electric steels are specified. Maximum limits are placed on sulphur and phosphorus.

Boiler and firebox steels Acid and basic open-hearth steels are specified. Limits of chemical analysis and physical tests are given by A. S. T. M.

Lap welded and seamless steel boiler tubes Carbon 0.08-0.18 per cent, open-hearth steel. Chemical and physical tests specified.

Welded steel pipe Bessemer or open-hearth steels are accepted.

Seamless steel pipe Open-hearth steel is required.

Cold finished Bessemer automatic screw stock The A. S. T. M. specifications require the following chemical specifications:

	per cent
Carbon	0.08 –0.16
Manganese	0.60 –0.80
Phosphorus	0.09 –0.13
Sulphur	0.075–0.15

Cold finished open-hearth automatic screw stock The A. S. T. M. specifications require the following chemical specifications:

	per cent
Carbon	0.15 –0.25
Manganese	0.60 –0.90
Phosphorus	Max. 0.06
Sulphur	0.075–0.15

It may be noted that both of the above specifications for screw stock allow a higher per cent of sulphur than would be accepted for other grades of steel. In fact, a minimum limit for sulphur is given for both steels and a low limit for the phosphorus of the Bessemer steel. Screw stock is practically the only kind of steel for which a certain amount of these embrittling impurities is actually demanded. The function of the sulphur is to make the steel "free cutting" or, in other words, to make it machine easier.

Such steels may be very desirable for screw machine products, such as nuts, bolts, and screws which do not have to stand heavy

loads in proportion to their size. They are not satisfactory for such parts as automobile spring shackle bolts, front axle spindle bolts, or other parts which receive severe service. They most decidedly cannot be recommended for case hardening or any other heat treatment involving quenching (with the exception of cyaniding for parts which do not require much strength).

S. A. E. steels 1010 and 1015, are low carbon steels with 0.10 and 0.15 per cent average carbon content respectively. The phosphorus is limited to 0.045 per cent maximum and the sulphur to 0.05 per cent. 0.30-0.60 per cent manganese is specified. These steels are recommended for tubing and many pressed steel parts. They are soft and ductile but do not machine so very well, as they are inclined to tear.

S. A. E. steel 1020, is similar to the two previously mentioned S. A. E. steels except that the carbon content is 0.15-0.25 per cent. It is sometimes sold under the name of "open-hearth machine steel." It machines better than the 1010 and 1015 and is somewhat stronger. It is much cleaner and sounder than screw stock. It is recommended for many forged and machined parts not requiring great strength. It will not stand quite as severe cold working as the lower carbon steels. It is one of the steels commonly recommended for case hardening.

Machine steel, and "cold-rolled" steel, are terms that are frequently heard in the shops but they are far from being definite specifications. Almost any kind of low carbon Bessemer or open-hearth steel which machines well may be classified as machine steel. It may be finished hot and consequently have a scaled surface. The term "cold-rolled steel," when used without any further description, usually means a low carbon steel which has been finished cold, that is, the bars have received the final passes through the rolls or dies while cold. Such bars have a smoother, more "shiny" finish and are more accurate as to size than the hot finished bars. The term "cold-rolled" does not tell anything as to the quality or freedom from impurities. It is dangerous practice to use steel purchased under such indefinite descriptions for case hardening or for parts which must stand severe service conditions.

0.25-0.55 Per Cent Carbon Medium Carbon Steels. This class includes a number of steels used for various purposes. In general these steels are stronger than the low carbon steels and

tougher than the high carbon ones. While the physical properties of the very low carbon steel are not greatly influenced by heat treatment, the medium carbon steels (particularly those containing 0.35 per cent carbon or more) respond quite readily to heat treatment. For many purposes these steels offer a better combination of strength and toughness than any other plain carbon steels. Consequently they are used for parts requiring considerable strength and toughness in proportion to their size. Certain alloy steels with a medium carbon content are even better in this respect. They will be discussed later.

The medium carbon steels also have some hardening power. This property increases with the carbon content. Consequently these steels may be used for parts which must stand some wear. However, they cannot be made sufficiently hard to serve as ball bearings, tools, or other parts which must be extremely resistant to wear. Certain alloys will increase the hardness. These steels are not as easy to machine as the low carbon steels, neither will they stand as much cold forming, even hot forging is somewhat more difficult. Beams, columns and other structural shapes for buildings and bridges are not made of medium carbon steel. On the other hand automobile front axles are forged from these steels. The reason for this lies in the fact that maximum strength and toughness and minimum weight is more important in automotive construction. In the case of building construction weight is not of maximum importance, and it is simpler to use the softer low tensile strength steels and make the parts correspondingly larger.

The exact properties of any steel in the medium carbon range will, of course, vary with the carbon content and the heat treatment. For steels which have received similar heat treatments, it may be said that the hardness, the tensile strength and the elastic limit (and the yield point) increase, and the ductility decreases with increase of the carbon content. Also the effect of the heat treatment on these physical properties increases with increase of the carbon content. For example a heat treatment consisting of a water quench from above the upper critical point, followed by a draw to 800 degrees Fahr., might raise the tensile strength of a 0.20 per cent carbon steel from about 65,000-70,000 pounds per square inch to about 75,000-80,000 pounds per square inch, while a similar heat treatment applied to a 0.45 per cent carbon steel might raise the strength from about 90,000-95,000 to about 120,000-

125,000 pounds per square inch. In other words the effect of the heat treatment is about three times as great for the 0.45 per cent carbon steel.

The following may be given as some of the examples of medium carbon steels and their uses.

Steel castings are made with varying carbon contents, with and without special alloys, but they usually fall in the low and medium carbon ranges. One of the common types of plain carbon steel castings contains about 0.25-0.30 per cent carbon. The physical properties of such castings may be greatly improved by annealing, normalizing and other heat treatments. Steel castings are made by the electric, open-hearth and Bessemer (or Tropenas, which is similar to the Bessemer) methods. Acid lined furnaces are the more common, although the basic method, particularly the basic electric, is used in the production of some types of castings. Open-hearth furnaces can be operated efficiently only in foundries having comparatively large tonnage production. The A. S. T. M. specifications allow as high as 0.07 per cent phosphorus and 0.06 per cent sulphur for acid steel castings, while the S. A. E. specification demands that sulphur and phosphorus shall be less than 0.05 per cent. Castings are frequently required to pass physical tests and are sometimes bought on physical tests only.

Bessemer railroad rails, according to the A. S. T. M. specifications, fall in four classes, with the carbon content varying from 0.37-0.55 per cent. A maximum phosphorus content of 0.10 per cent is allowed. The open-hearth steel rails with higher carbon and lower phosphorus contents are probably much more commonly used at the present time.

Railroad axles, piston rods and many other forgings are made of medium carbon steel, sometimes containing special alloying elements. Open-hearth and electric furnace methods of manufacture are specified. The requirements for carbon content vary from 0.25-0.70 per cent (0.30-0.55 predominating), depending upon the part. The specifications for tensile strength vary from about 70,000-125,000 pounds per square inch. Axles may be cold-rolled to produce the required physical properties. Heat treating of some parts is demanded.

Automotive parts which are made of plain carbon and alloy steels with a medium carbon content are almost too numerous to mention. Axles, shafts, universal joint parts, some gears, and

other parts which must withstand heavy loads in proportion to their size fall in this class. They may be made from forgings or bar stock. The steel for these parts is usually purchased under rigid chemical specifications. The great majority of automotive parts are heat treated in some way to produce the required physical properties.

Medium High Carbon Steel (0.55-0.75 Per Cent Carbon). Open-hearth railway rails, solid wrought wheels and tires are examples of this class of steels. Such articles must withstand heavy loads without deformation and must be fairly resistant to wear. Obviously rails cannot be quenched and drawn as automotive parts are, to produce the required high elastic limit and resistance to wear. Consequently comparatively high carbon steels are used.

The specified carbon content for the four grades of open-hearth rails varies from 0.50-0.75 per cent. The maximum phosphorus allowance is 0.04 per cent. The specifications for carbon for the several classes of wheels are 0.60-0.85 per cent and for the different classes of tires, 0.50-0.85 per cent. Sulphur and phosphorus contents are limited to 0.05 per cent. Open-hearth and electric furnace manufacture are approved.

High Carbon Steels (0.75 Per Cent Carbon and Higher). High carbon steels are used primarily for tools but are also employed for some other parts requiring either high elastic limits or resistance to wear. Among these may be mentioned the plain carbon spring steels and the ball race steels.

Plain carbon spring steels may contain from 0.85-1.15 per cent carbon. They are usually made by the open-hearth or electric methods. The sulphur and phosphorus contents are held low. They are heated, quenched, and drawn to produce the required physical properties. Alloy spring steels usually fall in the medium carbon class. The alloying elements help to produce the high elastic limit without the carbon being so high.

Steel for cups, cones, and ball races may have a carbon content varying from about 0.90-1.25 per cent. These steels frequently contain 1.00 per cent or more of chromium, which increases the strength and the hardening power. Ball bearings are also made of low carbon steel with or without special alloys and are case hardened.

Plow shares, jail bars and some other articles may be made of steel which is composed of both high and low carbon steels fused

or welded together. Such steels may be produced by either of two methods. For example, two layers of high carbon steel with a layer of low carbon steel between them may be heated and welded together and then be forged to the desired shape to form the plow share. In this way it is possible to produce hard outer surfaces and a soft tough center or core. Jail bars may be produced in the same way, except that more than three layers of steel are welded together. After being forged to shape the bars may be hardened. Thus bars are produced which are too hard to saw and at the same time too tough to break. The other method may be called the soft center ingot method. In this method a small low carbon steel ingot is placed in a larger mold and a high carbon steel is cast all around it. The large ingot thus formed is forged to the desired shapes. As the outer layers are high in carbon they may be hardened without greatly affecting the properties of the soft core, which is too low in carbon to be hardened by heat treatment.

Summary

As was stated in the beginning, this article has been written from the standpoint of the consumer. No attempt has been made to give a detailed technical discussion of the methods of manufacture. It has been attempted to point out the difference in the properties which may be expected in steels of different carbon contents and different methods of manufacture. It is obviously impossible in an article of this length to cover all of the different steels and their uses. It has been attempted to pick out typical examples of the different classes. The main points covered may be summarized briefly as follows:

A complete description of any steel must include the method of manufacture as well as the chemical composition. As a general rule the steel making methods may be rated in the following order: basic electric, acid electric, acid open-hearth, basic open-hearth, acid Bessemer, but in the final analysis much depends upon the skill of the melter. The more drastic the requirements of service, the cleaner and sounder the steel should be. High sulphur and phosphorus steels are recommended for screw stock but not for parts requiring strength. The strength, elastic limit, hardness, and hardening power increase with increase of the carbon content, while the toughness decreases. For any particular job there is a type of steel which is the most desirable.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses

DISCUSSION OF E. C. BAIN'S PAPER ENTITLED "THE NATURE OF THE ALLOYS OF IRON AND CHROMIUM"[1]

Written Discussion:—By Dr. Zay Jeffries, Cleveland.

I DO not wish at this time to enter into a discussion of the many interesting scientific aspects of this paper, but desire only to call attention to certain of the broad aspects of what seems to be a new step in the field of ferrous metallography. The field embraces not merely the retention of so-called delta iron solid solutions, at low temperatures, but the practical heat treatment of these solid solutions. In other words, there has recently been developed what may be termed a new art in steel treating in which gamma iron plays no part. To the best of my information, the originator of this art is W. P. Sykes.

The following is quoted from the first Robert Henry Thurston lecture on "Engineering and Science in the Metal Industry" delivered by me on December 3, 1925, at the annual meeting of the American Society of Mechanical Engineers in New York City and published in the January, 1926, number of *Mechanical Engineering*.

> "The following statement made by Bradley Stoughton in his Metallurgy of Iron and Steel, page 403, fairly represents the state of the art with reference to the role of carbon in high speed steel as well as other steel.
>
> "'It is commonly stated in the trade that tungsten will take the place of carbon in producing hardness, but this is not true. It is far more correct to say that tungsten will assist carbon in producing hardness, and therefore, with high tungsten steels we may have lower carbon. The distinction may appear merely academic, but it is well worth recognition by those who expect to make a study of these steels. No amount of tungsten or any other element will make steel hard in the absence of carbon, or even when the carbon is low.'
>
> "Mr. W. P. Sykes, Cleveland Wire Works, Incandescent Lamp Department, of the General Electric Co., has recently made a development which changes this art. If about 22% of pure molybdenum is added to pure iron it is found that the molybdenum is soluble in the iron at a temperature of say 1400° Cent. On slow cooling, a compound of iron and molybdenum separates out in relatively large particles and the resulting alloy when cooled to room temperature is

[1] TRANSACTIONS of American Society for Steel Treating, Vol. 9, January, 1926, pages 9 to 32.

not very hard. The microstructure of this iron molybdenum alloy after being slowly cooled, is shown in Fig. 13.

"When the alloy was quenched from the high temperature and solid solution preserved at room temperature, the Brinell hardness number in one instance was 214. This material is coarse-grained, as shown in Fig. 14.

"Gamma iron plays no part in this system, the alloy retaining the body-centered cubic space lattice from room temperature up to the melting point. This quenched solid solution is supersaturated in molybdenum. On reheating to 600 to 650 deg. Cent. it is possible for the molybdenum atoms to diffuse in the iron space lattice and a portion of the molybdenum combines with some of the iron to form small (critically dispersed) particles of hard iron-molybdenum compound. Such an alloy heated for 60 hours at 600 deg. Cent. showed a Brinell hardness of 531, which is comparable to that of the hard steels. Not only is the hardness comparable to that of hard steels, but certain dies made of this alloy operated at a high temperature, showed up to 60 times the life of the best high speed steel. The microstructure of the alloy in the hard state is shown in Fig. 15."

I should like to call especial attention to Bain's Fig. 7. The region of this diagram marked "Austenite" indicates that with negligible carbon the iron-chromium alloys containing less than about 14% chromium, will, when properly cooled, from a high temperature (above about 1450 deg. Cent.) transform from a body-centered cubic to a face-centered cubic space lattice, and then back to a body-centered lattice again. It also indicates that with more than about 14% chromium only one type of crystal structure obtains unless carbon is present.

As is shown in the preprint of the paper by Sykes, "The Iron-Tungsten System" to be given at the annual meeting of the American Institute of Mining and Metallurgical Engineers in February, 1926, this identical phenomenon is shown in the carbon free alloys of iron and tungsten. While Mr. Bain has been aware of these results of Sykes' for a good many months, he quite properly avoided mention of this information which he no doubt regarded as confidential.

It might be mentioned that the "earlier work" described in Bain's paper on page 10 of the January issue of the TRANSACTIONS of the A. S. S. T. was done by Bain when he was connected with the Cleveland Wire Division of the General Electric Co.

I know that the other members of this Society will join me in welcoming the advent of this new science and art in the field of steel treating.

Oral Discussion

B. H. DELONG: I would like to ask how long the pieces from which the micro-sections were taken were held at heat before quenching?

E. C. BAIN: They were usually held at temperature about 45 minutes—a few I believe were held an hour. This is a rather long time, but there was a reason for this procedure. We wished to grow large grains and coalesce all

constituents into large particles in the interest of easy identification of structures. Mechanical properties were sacrificed as this was primarily a study of microscopic structure.

H. M. GERMAN: I would like to ask Mr. Bain if delta iron is formed when hardening high speed steel at a sweating heat?

E. C. BAIN: I cannot say positively that delta iron is not formed in high speed steel at that high temperature. We should probably answer that question most definitely by holding a piece of high speed steel wire at high temperature and obtaining its X-ray pattern. I am inclined to believe that the carbon content of high speed steel is too great to permit the existence of delta iron. At any rate the higher the quenching temperature the greater is the proportion of austenite found after the quench,—a circumstance which argues strongly against any delta iron.

H. M. GERMAN: I would like to ask another question: how do the physical properties of quenched and drawn delta iron steel or alloys compare with the same steel in which you get, the same microstructure, in quenching? For example, in a paper you gave in Cleveland last September, "On the Nature of Some Low Tungsten Tool Steels," you showed that austenite was produced at the higher quenching temperatures and on drawing there was a secondary hardness produced by the change of this austenite to martensite? We find that when austenite is produced in quenching and then brought back to martensite by drawing, the physical properties of this martensite, particularly with the higher carbon, and also chromium content, are entirely different from the martensite that you obtain in direct quenching. It may show the same Rockwell hardness, but when tested with file or service test, it is entirely different. Have you made any tests to compare the physical properties of the delta iron when drawn back?

E. C. BAIN: In the first place, delta iron which is "drawn back" is still delta iron—or the same thing exactly—alpha iron. As the slide of photomicrographs shows, nothing happens during the reheating except perhaps the precipitation of a small amount of carbide. Delta iron at room temperature is truly stable.

H. M. GERMAN: Another question I would like to ask, what etching reagent did you use in the preparation of the samples for microscopic examination?

E. C. BAIN: We etch with aqua regia and glycerine, prepared by mixing one part nitric acid with two or three parts hydrochloric acid and then adding a volume of glycerine equal to the acid mixture. Polishing many of the alloys is very difficult—many were satisfactory only after four successive polishings and etchings.

J. V. EMMONS: In regard to the question as to whether delta iron occurs in high speed steel, I would like to remark on some observations which we made about 1914 or 1915, while investigating high speed steels of low carbon content. We found with a steel of a carbon content of about 0.40 or 0.50, per cent when heated to the melting point, or very slightly below it, and quenched with great rapidity in iced brine, that a constituent was developed, the nature of which we were not able to determine. It appeared

very much like ferrite. It had a polyhedral grain structure, and was apparently very soft, and, therefore, of no use for tool making purposes. Its structure was not affected by any subsequent drawing treatment. Not knowing its nature at that time, we called it constituent V. I am glad to say that this work of Mr. Bain's is a real intimation of the nature of this constituent which I now believe must have been delta iron.

E. C. BAIN: This question lies distinctly in the scope of the splendid paper by Mr. Sykes which I have mentioned already. As his paper for the A. I. M. M. E. has already been preprinted perhaps he will, if present, answer the question himself.

W. P. SYKES: I do not care to make any discussion at this time. In connection with that note of Mr. Emmons though, it seems to me with the carbon, as you said, around 0.40 or 0.50 per cent, from what I have seen in a little preliminary work on the effect of carbon on that steel, that carbon content seems a little bit high to allow any delta iron to form, although I would not hazard much of a guess on it at the present time.

DR. J. A. MATHEWS: Possibly that might be explained by the fact that the initial bar contained 0.40 to 0.50 per cent carbon, but after it had been heated to the melting point some carbon was lost.

I merely want to add a word in appreciation of this very beautiful investigation Mr. Bain has given us here today. It will be well worth the members' while to study this paper in conjunction with that of Mr. Sykes. It represents a new state of progress in the art. I would like also to suggest that now it might be timely to go over and revise several of those simple constitutional diagrams which we have been brought up on in the study of metallurgy,—the Guillet diagrams. I think that might be a good project for a committee to handle and reproduce some diagrams for purposes of verification as to how true our present knowledge is, as represented by those very simple things we have had for about twenty years.

JEROME STRAUSS: Aside from the notable achievement of having retained delta iron at room temperature in these alloys, there is so much of immediate technical value that most of us who are dealing, not with delta iron, but with the chromium steels, can well afford to give considerable thought to Mr. Bain's paper. One can readily perceive the possibility of clarifying some of the peculiarities which arise in the every day use of the large number of alloys of varying carbon and chromium content which have now found their way to us commercially.

Mr. Bain mentioned in his paper that in his experiments he did not find any evidence of pearlitic formations above about 10 per cent chromium. With suitable cooling rates not particularly slow (about 2200 to 900 degrees Fahr. in 14 hours) I have found pearlitic areas in steels of 0.25 to 0.50 per cent carbon and about 20 per cent chromium. These are illustrated in Figs. 1, 2 and 3 of this discussion.

I should like further to ask Mr. Bain whether it would not have been possible, without the introduction of other troubles, to have used a more suitable medium than hydrogen for the furnace atmosphere when heating for quenching.

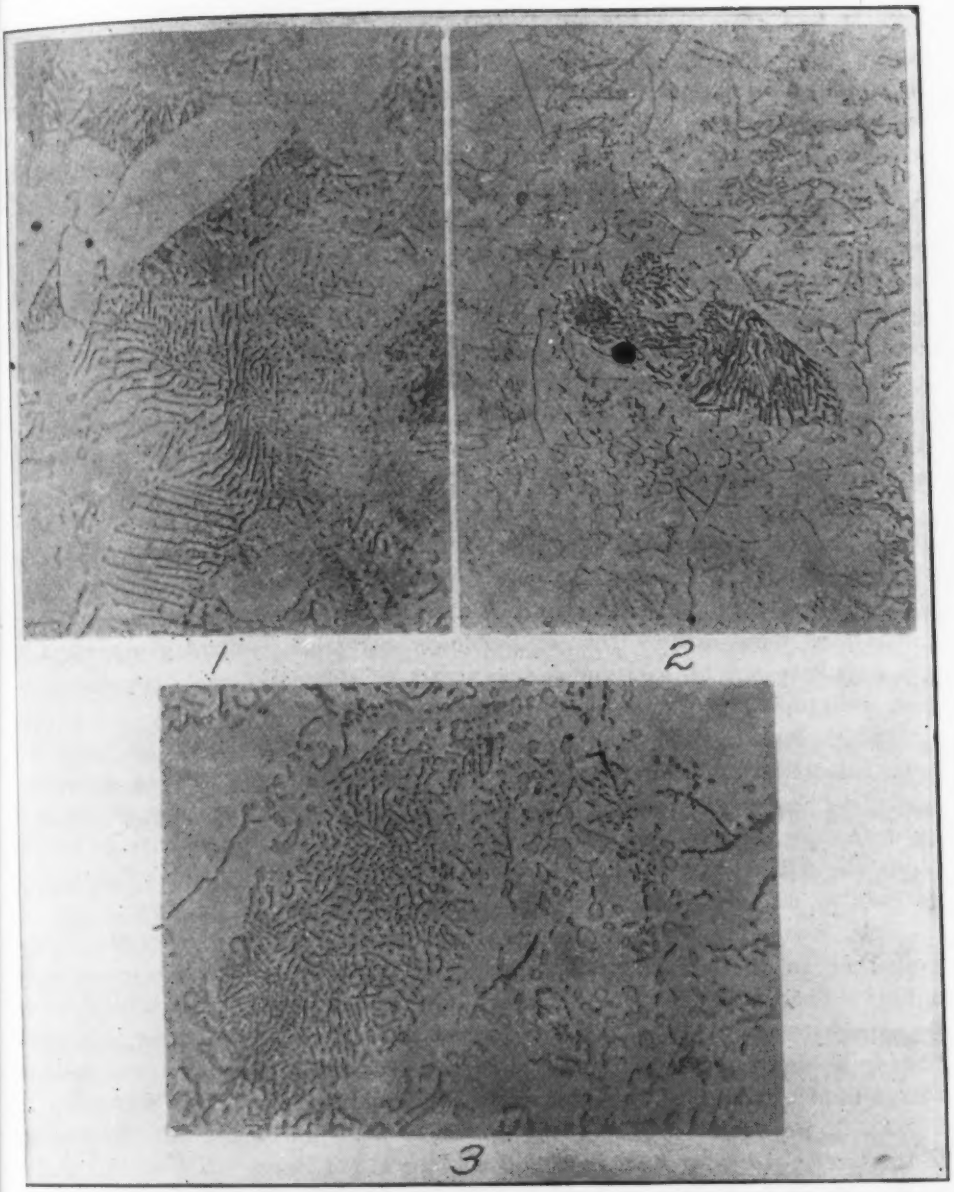


Fig. 1—Photomicrograph of a Chromium Steel having a Carbon Content of 0.24 per cent and a Chromium Content of 20.4 per cent Heated to 2200 degrees Fahr. for 30 Minutes and Furnace Cooled. Mag. 500X. Fig. 2—Photomicrograph of a Chromium Steel having a Carbon Content of 0.50 per cent and a Chromium Content of 20.0 per cent Heated to 2200 degrees Fahr. for 30 Minutes and Furnace Cooled. Mag. 500X. Fig. 3—Photomicrograph of a Specimen Similar to Fig. 2—having the Same Analysis and Same Heat Treatment. Mag. 500X.

E. C. BAIN: I intended to mention having seen some of Mr. Strauss' photomicrographs covering a few of the alloys discussed today. Among his excellent collection were beautiful photographs of pearlite in the higher chromium alloys obtained no doubt by a somewhat more rapid cooling, during the anneal, than I used. It was interesting to see pearlite developed in these alloys by proper choice of annealing schedule.

It was unfortunate I am sure that I used a hydrogen atmosphere in all this work but it was only in a furnace which necessitated the hydrogen that I could obtain close temperature control. The decarburization was more severe—as I mentioned—than we suspected, even with the warning of other experimentation, and consequently some of the specimens which yielded pure delta iron at high temperatures, are not strictly correct for the carbon content indicated. The delta iron grains would have exhibited some intergranular austenite with medium chromium.

W. J. MERTEN: I would like to ask Mr. Bain whether he noticed or found greater chemically inert properties in delta iron of high chromium low carbon steel and high speed steel and somewhat less chemically inert characteristics of the higher carbon ranges which result in formation of austenite?

E. C. BAIN: I did not attempt to correlate corrosion resistance with delta iron. It would however be very much like the thoroughly annealed alloys I would suppose.

MR. KNIGHT: I would like to ask a question of Mr. Bain. I understood him to say the delta iron, once formed, was comparatively stable, and there would be no change, in your answer to Mr. German's question. How does it come then that upon heating at different temperatures and quenching from these temperatures, that in the lower chromium content you are able to get austenite out of solution and mixtures of austenite, and then delta solution and then the higher temperatures?

E. C. BAIN: Delta iron and alpha iron are identical physically, and one may substitute the word "alpha" for "delta" in any of the statements regarding its metallographic behaviour. In order to produce any change in it even though quenched from the very high range one would have to heat it above the critical range. Then austenite would result which would be quenched as such or as martensite depending upon composition.

MR. KNIGHT: Well, would reheating them up to the edge of the critical range, or in the critical range, bring it back to the austenitic condition again? Then it seems to me from a physical chemistry viewpoint it would be considered to be a metastable rather than a stable condition. In other words, if delta solid solution can, by reheating, be transformed back to austenite solid solution, then this delta solid solution must be a later state.

E. C. BAIN: It can be transformed back to austensite only by heating to the temperature for stable austenite. This is not in any sense a "drawing" operation: it is merely heating to alter one stable phase to another stable phase. In organic chemistry there are analogous binary mixtures which exhibit similar conditions.

J. V. EMMONS: Mr. Chairman, I would like to ask Mr. Bain if he has made any observations of the stainless properties of delta iron as compared with austenite or martensite in the high chromium steels.

E. C. BAIN: Yes, actually I have made some study of such properties but it is all without the scope of this paper, and I prefer not to discuss it at this time, if you will excuse me.

DR. J. A. MATHEWS: I would like to ask one more question, Mr. Bain, is there any composition or quenching temperature at which any of your

chromium steels approach the non-magnetic state?

E. C. BAIN: Yes, I have some wholly austenitic alloys of iron, chromium and carbon. I showed a slide from a photomicrograph of such an alloy. It was entirely non-magnetic and was used in the drawing experiment described and for X-ray examination.

MR. KNIGHT: What was the form of the specimen that you used for the X-ray spectrum?

E. C. BAIN: A solid sample cut out of the specimen bar by means of the cut-off wheel.

Author's Closure

The appearance of the preprint of a paper, "The Iron-Tungsten System," by Mr. W. P. Sykes, gives me the privilege and opportunity of expressing my admiration for this work and of acknowledging the encouragement I derived from having private communications from Mr. Sykes concerning his research. There is a similarity between the alloys containing up to about ten per cent tungsten and certain alloys of iron and chromium. By means of thermal analysis Mr. Sykes found the boundary of the austenite region to be a sort of loop and when the microscope showed that the region for austenite formation in chromium iron alloys was similar the analogy came to mind. As the finding is somewhat unique the idea of the preservation of delta iron by quenching from *above* the region of austenite stability was pleasantly fortified by Sykes' experiments in the other system.

Since the publication of the approximate constitution diagram of the iron-chromium system the writer has discovered that decarburization proceeds rather more deeply than was expected and in a somewhat different manner. Consequently for alloys containing higher carbon content—above 0.20 per cent—the diagram should show that the delta iron is mixed with some austenite in the grain boundaries which persists very tenaciously practically to the melting point of the alloys. The diagram seems correct however for negligible carbon content.

DISCUSSION OF H. B. KNOWLTON'S PAPER ON "FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—PART IV"[1]

BY C. G. WILLIAMS[2]

IN the January issue of TRANSACTIONS H. B. Knowlton makes the following statement:—"Steels containing from 1.00 to 2.00 per cent manganese are usually quenched in oil instead of water to avoid producing brittleness. Steels containing from 2.00 to 7.00 per cent of manganese and no other alloy are very brittle and are not used. High manganese steels containing 12 per cent manganese and 1.25 per cent carbon are quite hard and are tough at the same time. They are used for railway switch points, cross-overs, ore crushing machinery and some other purposes."

[1]H. B. Knowlton, "Facts and Principles Concerning Steel and Heat Treatment—Part IV," TRANSACTIONS, American Society for Steel Treating, Vol. IX, No. 1, page 111.

[2]The author of this discussion, C. G. Williams, is mechanical engineer, Barber Colman Company, Rockford, Ill.

It is believed that Mr. Knowlton is but furthering the common superstition or belief that manganese contributes an embrittling effect on steel—which is not the case. Because a severe water quenching has apparently caused a manganese bearing steel to crack is no criterion that the manganese was the cause of the cracking for plain high carbon steel will likewise crack if given a too drastic quenching in water. The cracking of any manganese steel in water quenching is the direct result of too high a temperature when working or in heating preparatory to quenching, for if the steel is not heated very slowly and uniformly, it is liable to crack while heating. It may only crack while heating, but the quenching process will cause it to split.

Since manganese forms with cementite a double carbide in steel, the effect is to increase the tensile strength of the metal. In untreated steel this beneficial effect is dependent upon the carbon content. In treated steel each 0.1 per cent of manganese, up to about 2.00 per cent, will increase the tensile strength by about 1500 to 2000 pounds per square inch. With a constant carbon content, the effect of increasing amounts of manganese is to increase the tensile strength and the Brinell hardness.

From tests made, it is evident that the tensile strength and elastic limit of manganese steel and nickel steel are practically alike but an excess of manganese exerts a strengthening effect equivalent to about three times the same amount of nickel, that is for a heat treated 1.5 per cent manganese with the manganese in excess of that contained in the nickel steel of a corresponding carbon content.

In treating pearlitic steels, attention should be called to the fact that each 0.1 per cent will lower the critical range on heating by about 5 to 6 degrees Fahr. so that lower temperatures may and should be used for hardening or for full annealing. Generally the effect of manganese on critical ranges is about twice that of nickel.

The writer has tested rifle barrels with from 1.00 to 2.00 per cent manganese—with 1.25 to 1.45 per cent manganese predominating—and given them a severe water quench. In the cases where a high temperature was used while working or just before the quench, there was a liability that the bloom of steel or the barrel would burst lengthwise or on the cross section as well, while if a low heat, say a dark red heat or 1290 to 1340 degrees Fahr., were used no barrels or blooms were cracked. It was found that these steels could all be heat treated to give high tensile strength and still be worked.

Up to late years it was seldom that a manganese steel with a low carbon content could be obtained because of the high carbon content of the available ferromanganese, which carbon added to that in the steel brought the carbon to a high percentage. Since a process has been perfected whereby a low carbon ferromanganese is available, it is found that with a carbon content of from 0.20 to 0.30 per cent, a manganese content of even 4.50 per cent will give a steel that when water quenched at from 1255 to 1340 degrees Fahr. will give high tensile strength and ductility of about 25 to 30 per cent in two inches and that is comparable in every respect with a corresponding nickel steel.

Late practice, that is, since 1916, has produced a manganese steel with a carbon content of 0.35 to 0.45 per cent and manganese 1.40 to 1.47 per cent

that when quenched in water from 1340 to 1380 degrees Fahr. gave a tensile strength of 90,000 to 100,000 pounds per square inch; 120,000 to 130,000 pounds per square inch elastic limit; 24 to 26 per cent elongation in 2 inches and a 50 per cent reduction of area. This would not indicate brittleness. However, the presence of manganese does make a steel susceptible to heat, and for best results both in working and heat treating, the temperatures should be held very close to the critical range. Personal preference would be to hold the temperature below the critical range while working the steel and only exceed the critical range when heating preparatory to treating.

High manganese steel, i. e., those at or above 9 per cent manganese with a carbon content of from 1.00 to 1.25 per cent, will, when cast, be as brittle as glass, but if allowed to cool thoroughly then heated to 1830 degrees Fahr. and plunged into cold water the resulting steel will be as ductile as wrought iron, while its tensile strength is about three times as great. These steels are tough, wear resistant, but are not hard. While they may be drilled or otherwise worked with difficulty, a light blow with a hammer will leave a considerable dent in the metal. Thus its Brinell hardness is comparatively low.

Recent research work has widened the commercial range of these steels, both with respect to the low manganese content steels and the high manganese steels.

There is also a popular conception abroad that manganese steels cannot be welded to other steels with success. Within the last two years such a view was presented to the writer when a certain railroad blacksmith foreman was asked to weld furnished bars of steel to a soft or low carbon steel back for dredge dipper teeth. The first attempt failed and gave a ruined bar of steel. Upon inquiry as to its action and an investigation of its qualities, it was declared to be manganese steel. Thereupon, the foreman was for scrapping the steel until he was shown that by bringing the low carbon steel back up to a white welding heat and the manganese steel to a dark red heat, they could be easily welded. The soft steel back welding itself to the manganese steel in a way that gave most successful results. *C. G. Williams.*

Author's Reply to Mr. Williams' Discussion

I have read with much interest Mr. Williams' discussion of my article published in the January issue of the TRANSACTIONS. Comment and criticism is always most welcome. Mr. Williams has brought up some interesting points concerning the effect of manganese on steel. While I may agree with him in part, I believe that some of his statements may possibly be open to dispute, at least I fear that the reader may draw some erroneous conclusions. Also I feel that my original statements can be justified.

The article which Mr. Williams criticised dealt primarily with some of the common types of tool steels. It was also attempted in a few words to describe the general effect of some of the alloying elements. It was to the few lines devoted to the effect of manganese, that Mr. Williams took exception.

The writer fully appreciates that it is difficult, if not impossible, to give a generalized statement in a few words which will accurately cover all

possible conditions. It is not claimed that the statement given was a complete treatise on the subject. The metallurgical literature of recent years has contained many pages concerning manganese. The reader of the TRANSACTIONS is referred to an article by Jerome Strauss in the issue of December, 1923, and to the article by Gill and Frost in the January, 1926, issue. It is worth noting that Mr. Strauss stated that it was difficult to cover the subject thoroughly in the necessarily limited space (44 pages).

Mr. Williams challenges the statement that manganese in certain proportions may produce brittleness. This he terms a "superstition." However, this superstition is based on reliable scientific data as well as practical experience. It seems to be accepted by some of our best authorities. Gill and Frost state that manganese has an embrittling effect on hardened high carbon tool steel and increases the danger of cracking. They recommend 0.30 per cent as the maximum limit in plain carbon tool steel. Dr. Mathews and Mr. Kingsbury challenged this limit, but apparently did not dispute the fundamental principle. The figures given by Strauss which are quoted herein show conclusively that manganese in certain proportions produce brittleness irrespective of the heat treatment.

The writer's statement that steels containing between 2 and 7 per cent manganese are brittle and are not commonly used, should perhaps be qualified as the amount of manganese necessary to produce the brittle condition varies inversely with the carbon content. The figures given were meant to apply to steels in the ordinary tool steel range. Lower carbon steels might contain more manganese without being inherently brittle. Extremely high carbon steels might be brittle with even less manganese.

This point can best be understood by studying Guillet's diagram of the constitution of manganese steels after forging and air cooling. See Fig. 1. (See TRANSACTIONS, A. S. S. T. Vol. 4, p. 681, December, 1923.) It will be noted that for steels containing less than 1.60 per cent carbon this diagram is divided into three large areas. Steels that fall in the upper area are composed of austenite. Those in the center area contain martensite or troostite, while those in the lower area contain pearlite. Thus a 1.00 per cent carbon steel containing roughly 2.00 to 5.00 per cent manganese, a 0.50 per cent carbon steel containing about 4.0 to 8.0 per cent manganese, and a 0.25 per cent carbon steel containing about 5.0 to 10.0 per cent manganese fall in the martensitic area. So far as the writer has been able to learn, steels of these compositions have not found commercial use. Although it might be inferred from Mr. Williams' statements that manganese has no connection with brittleness, it may be noted that he is silent concerning manganese steels of the composition just given.

The fact that steels which contain carbon and manganese in such proportions as to place them in the martensitic zone of Guillet's diagram are brittle is quite conclusively shown by the data given by Strauss (see TRANSACTIONS, A. S. S. T., Table VII, p. 679, Vol. 4, December, 1923). Steels of these compositions showed less than 6 per cent elongation and less than 9 per cent reduction of area, regardless of the heat treatment given. It may be possible that the exact position of the lines on Guillet's diagram may some

day be disputed, but the fundamental principles are quite well established.

The data given by Strauss also confirms the fact that the high manganese austenitic steels and the lower manganese pearlitic steels are very tough when properly treated.

Mr. Williams correctly states that there is a similarity between the effects of manganese and nickel. He also points out that manganese together with the iron forms a double carbide. It may well be added that in the latter respect the action of manganese is quite different from that of nickel. It is more similar to the action of chromium. Might it not be better to compare the pearlitic manganese steels with the chromium-nickel steels instead of the straight nickel steels?

With regard to oil and water quenching of steels containing between 1.0 and 2.0 per cent manganese, the writer believes there is ample justification for the advice to quench in oil. The nonshrinking tool steels fall in this class. These are sometimes called "oil hardening tool steels." The writer does not know of a single steel company which recommends water quenching of such steels. In fact, he has never been able to find that there would be any advantage of water quenching. Many tool hardeners can testify to the disastrous results sometimes obtained by so doing.

It is true that medium and low carbon pearlitic manganese steels may be quenched in water successfully. However, it is also true that many prefer oil quenching. The writer recently received from one of the steel companies which specializes in alloy steels a sample of their manganese steel which they are particularly pushing. The composition was 0.43 per cent carbon, 2.03 per cent manganese. Their letter recommended *quenching in oil* from 1550 degrees Fahr. and drawing as required.

The writer has obtained some very satisfactory results in case hardening steels containing over 1.0 per cent manganese, giving the final quench in water. As Mr. Williams states the final quenching temperature must be lower than that used for plain carbon steel. It might be asked if such a treatment did not produce a brittle case. If such brittleness was produced, it was overcome by the great strength and toughness of the core. In spite of this, the writer believes that oil quenching might better be advised in the instances.

Mr. Williams challenges the statement that the high manganese high carbon steels are both hard and tough. He mentions the fact that such steels in the cast condition are quite brittle, which is true. However, the same may be said of most of the high carbon steels with or without alloy content. There may be varying degrees of brittleness, but in general it may be said that most steels are more brittle in the cast untreated condition than in the forged or heat treated condition. When the writer has described a steel as tough he has expected it to be understood that it is tough when in the condition in which it is ordinarily put into service.

Mr. Williams' statement that the high manganese steels are hard but are wear resistant brings up the old question of what hardness is. From a practical viewpoint it may be more important to consider the type of hardness which involves resistance to wear rather than resistance to indentation. Sometimes both are required. Unfortunately resistance to wear and resistance

to indentation do not always go together. The indentation machines such as the Brinell, the scleroscope and the Rockwell may give misleading information if this point is not considered. The Brinell hardness of a high manganese steel may not exceed 200 and yet such a steel may prove extremely resistant to certain types of wear.

Both the present writer and Mr. Williams may be criticized for stating that these steels are resistant to wear. Strauss mentioned that the high manganese steels may be hardened by the cold work they receive in service. This is a very important point. In this connection a manufacturer of steam shovels has reported that manganese steel is good for dippers working in gravel, but not satisfactory for shovelling loose sand. The former case involves both wear and hammering (or cold work) while the latter involves wear or abrasion only.

The writer acknowledges that his first statements concerning the effect of manganese were too brief to cover every possible condition. It has been attempted to make this reply as brief as possible. Although it is many times the length of the original paragraph it also may fail to cover the case on account of necessary brevity. For more complete information, the reader is again referred to the rather voluminous literature on manganese steels.

H. B. Knowlton.

WRITTEN DISCUSSION OF PAPER BY DR. H. HANEMANN AND A. SCHROEDER, ENTITLED, "ON MARTENSITE"[1]

BY C. G. WILLIAMS[2]

IN attempting to reconcile past and present studies with the hypothesis presented by the authors, there is much to commend and much to oppose. It would seem that this hypothesis is exactly at the point where so many of the past hypotheses have been—merely a passing attempt to read into a structure of steel much that should be considered in other lights.

The opposition to the outlined theory and hypothesis is in the belief that what is claimed to be separate structures and separate formations—therein designated as Epsilon and Eta formations—are but transition points between the Beta and Alpha phases of the metastable carbon-iron diagram—*Howe*—The Metallurgy of Steel and Cast Iron—*Sauveur*—Metallography and Heat Treatment of Steel—and that they should be considered as such.

It was but a few years ago that some experimenters were clamoring for a separate structure and formation hypothesis to determine and account for the status of hardenite, which most authorities now consider as properly that transition stage between austenite and martensite that is sometimes called austenite-martensite, or austenite plus martensite.

It is well known that austenite is mineralogically softer than martensite and that there is a point in the transition stage during the transformation from austenite to martensite where the steel has an apparently different structure from either austenite or martensite. Also at this point some specimens

[1]TRANSACTIONS, February, 1926, Vol. IX, pages 169-239.

[2]Mechanical Engineer, Barber-Colman Co., Rockford, Illinois.

(Continued on Page 331)

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

YIELD POINT, COLD AND HOT BRITTLENESS. By P. Ludwik, Wien. Zeitschrift des Vereines Deutscher Ingenieure, March 20, 1926, p. 379-386.

The yield point of electrolyic iron and mild steel and the change of it by aging and by critical stretching and annealing, the hot brittleness (blue brittleness) and the phenomena during the hardening of steel and aluminum alloys are considered as after-hardening phenomena and reduced to changes of solubility.

The cold brittleness and the dependency of the impact value from the notch and the form of the test piece, from the velocity of shock and from the temperature are deduced from the change of the slip and tearing resistance and from the stress condition.

The author discusses the importance of tensile tests on notched bars, with very sharp notch, for the determination of the tearing strength. The influence of the breadth and depth of the notch is discussed by comparing tensile tests, tensile tests on notched bar and shock tests on notched bar.

By pickling mild steel, the tearing test decreases owing to absorption of hydrogen, but the yield point and the tensile strength are unchanged.

Caustic embrittlement presents, if the tearing strength is decreased by absorption of hydrogen and the slip resistance is increased by aging at existing stretching-heat stresses.

Abstracted by Dr. Hans Pollack, Germany.

MAGNETIC CHANGES IN IRON AND STEEL BELOW 400 DEGREES CENT. By W. H. Dearden and C. Benedicks. Preprint, British Iron and Steel Institute, May, 1926.

In this paper the authors give the result of their investigation on the low-temperature changes in iron and steel by a magnetometric method in which the specimens were heated while suspended at an angle of 45 degrees to a constant magnetic field of 15 gausses. The complicated apparatus used in the experiment is described and the results given. Temperature-magnetization curves were photographically registered.

ELECTRIC HEAT FOR THE MACHINE SHOP. By P. F. Creasy. In *American Machinist*, June 3, 1926, page 865.

This article sets forth the importance of electric heat in the industrial world, its variety of applications and its advantages.

The author is of the opinion that cost is only one factor, and while it may cost more to operate the electric furnace yet it has many advantages which tend to offset this factor. It is more compact, quiet in operation, requires less

floor space, produces better working conditions, reduces fire hazards, gives continuity of service and is adapted for automatic control and consequently improved quality and uniformity of product, with reduction of rejections, and greater output result.

He also describes a practical construction for heating to various heats and says that the installation must be economically justified and only adopted after a careful study of all the facts warrant it.

POINTING WIRE BY ELECTRICITY. By A. R. Petterson. In *Wire*, May, 1926, page 11.

This article describes in detail the method of producing a true point in wire drafting and points out the superiority of using electricity over the old way of filing or rolling. It also sets forth the economy resulting from this method in dies and scrappage of wire. Wires high in carbon content are more easily pointed than soft wires, because the former are more resistant, is the author's opinion.

GETTING THE BEST OUT OF DIAMOND DIES. By B. J. Boulin. In *Wire*, May, 1926, page 17.

This articles enumerates the common-sense rules which, if followed, will, in the author's opinion result in the maximum service.

PHOSPHORUS AFFECTS QUALITIES OF GRAY CAST IRON—I. By John W. Bolton. In *Foundry*, May 15, 1926, page 378.

The author describes this element and where and in what form it is found in Nature. He says that in this country all iron-bearing ores contain some form or admixture of calcium phosphate. He describes the methods of its reduction and enrichment—depending upon whether high or low phosphorus pig irons are desired.

He describes the basic steel making processes used in the basic open-hearth or basic electric furnaces by which phosphorus can be eliminated. In the acid Bessemer, acid open-hearth and crucible processes the reduction of phosphorus is impossible hence pig iron low in phosphorus is used where phosphorus is not desired.

Continuing, he discusses the influence of phosphorus on cast iron and the iron-phosphorus diagram. He is of the opinion that one of the significant effects of phosphorus is its lowering of the iron carbon eutectic. In conclusion, he says that phosphorus has little effect either in increasing or diminishing graphite, consequently it has little influence on shrinkage.

The article is illustrated by numerous photomicrographs and diagrams.

TEMPERATURES IN THE HEARTH-ROOM OF AN OPEN-HEARTH FURNACE. By Dipl.-Ing. H. Wilhelm, Brandenburg, a. d. Havel. *Transactions*, Steel Works-Committee of the Verein deutscher Eisenhüttenleute.

The measurements of temperature were carried out on three open-hearth furnaces of 50-tons capacity, with the aid of Holbourn-Kurlbaum pyrometers. Making measurements while melting down the charge is very difficult because deflected flame gases make it difficult to ascertain the surface temperature; also great difficulty is encountered in the measurement of the flame and bath

temperature, owing to the flare of the flame and to the combustion of carbon monoxide.

The measurements were accomplished on rapid, normal, and slow melting furnaces to show the fluctuation of temperature by the changes of the furnace.

The results are: After tapping, the hearth temperature was 1550 degrees Cent. (2822 degrees Fahr.); in this time the upper part of the furnace has a temperature of 1650 degrees Cent. (3002 degrees Fahr.). During charging the average furnace temperature decreases to 1500-1550 degrees Cent. (2732-2822 degrees Fahr.) according to the speed of charging. After charging the increase of temperature of the upper part of the furnace amounts about 1 degree Cent. per minute. Perhaps an hour before melting down, the maximum temperature of the roof of about 1720 degrees Cent. (3128 degrees Fahr.) is attained. By gas throttling, charging of ore, chalk and ferromanganese the temperature decreases to about 1650 degrees Cent. (3002 degrees Fahr.). At hot heats the upper part of the furnace attains mostly the surface temperature of the bath. The flame temperature moves within the bounds from 1700-1880 degrees Cent. (3092-3416 degrees Fahr.). Charging the furnace the flame temperature is low. The maximum temperatures appear mostly towards the end of melting down.

Abstracted by Dr. Hans Pollack, Germany.

SIEMENS-REGENERATIVE CONTINUOUS FURNACE, FIRED WITH WASTE GAS AND DIVISION OF FLAMES. By Oberingenieur A. Sprenger, Berlin. *Stahl und Eisen*, March 18, 1926, p. 361-368.

The furnace described in this paper was built in the plant of the Hauts Fourneaux et Aciéries de Differdange at Differdingen. The furnace plant, being quite extramural of the rolling mill serves a continuous small mill. The charge consists of ingots from 6x6x85 inches, weighing about 900 pounds.

With this furnace a production of from 34.6 to 57.0 tons per hour were attained in continuous action at the most efficient gas-consumption and smallest iron waste. The utilization of waste heat, the mechanical attendance and the arrangement of slide rails in the furnace are described. The furnace and the type of slide bars are protected by German patents.

Abstracted by Dr. Hans Pollack, Germany.

FUNDAMENTALS OF DIE CASTING. By S. A. Hellings. In *Foundry*, June 15, 1926, page 472.

The paper deals with the process of casting metals in permanent dies under comparatively high pressure. This definition would indicate that die casting has limitations. The shape of the casting is at present a limiting factor. The size and weight of castings is increasing constantly. Alloys which melt below 1400 degrees Fahr. are those which have been successfully die-cast on a commercial scale. Mass production reduces the cost of die casting. In die casting, the construction of the die is of paramount importance. The parting line, the cores, the runners, waterways, gates and vents must all be accurately located.

In Fig. 2, the author, shows by diagram the principal parts of the vertical type of die casting machine. In this, the lower half of the die is stationary. The method of operation is set forth in detail.

Continuing the writer enumerates the 4 types of alloys used in die castings and describes when and how to use them.

He also says that many parts used in the manufacture of the radio are die-cast.

HARDENING AND TEMPERING PHENOMENA IN ALUMINUM ALLOYS. By Dr.-Ing. K. L. Meissner, Deutsche Versuchsanstalt für Luftfahrt, Berlin-Adlershof. Zeitschrift des Vereins Deutscher Ingenieure, March 20, 1926, p. 391-401.

In this paper the author discusses all the investigations, made hitherto, to clear up the question of duralumin, an alloy consisting of aluminum, 3.5 to 4.5 per cent copper, 0.5 per cent magnesium and 0.25 to 1.0 per cent manganese. On such an alloy, the inventor Wilm discovered the phenomenon of aging. He supposed that magnesium produces the improvement and also stated that the most favorable percentage of magnesium is about 2 per cent.

In 1919 Merica found that copper is the most important component of the alloy. The solubility of copper in aluminum decreases in the solid state with falling temperature; this decreasing is expressed in the aluminum-copper diagram by the separation line, defining the range of the solid solution of $CuAl_2$ in aluminum from the range comprizing the heterogeneous mixture of mixed crystals and $CuAl_2$. By annealing at a temperature above this line, the copper is dissolved in aluminum; by quenching the alloy in water this solid solution is retained at room temperature. If kept some days at room temperature the stable state of the alloy is formed and Merica supposes that the increasing of hardness, connected with this procedure, is produced by the separation of $CuAl_2$. Merica has also substituted the ordinary aging at room temperature for the so-called artificial aging at higher temperature. The results of this aging method are:

(1) The increasing of hardness grows with the raising of the aging temperature.

(2) The maximum of hardness is attained by aging above 100 degrees Cent. (212 degrees Fahr.).

(3) At aging temperatures above 140 degrees Cent. (284 degrees Fahr.) it is possible that the hardness decreases after reaching a maximum.

(4) At aging from 100 to 150 degrees Cent. (212-302 degrees Fahr.) the elongation rests almost unchanged, but decreases on less than the half quantity if higher aging temperatures are used.

Further, Merica concluded that there is a certain size of $CuAl_2$ particles on which the hardness and the strength of the alloy attain a maximum; this size was called by Z. Jeffries and R. S. Archer as critical dispersion.

After some time W. Fraenkel stated the fact, that in the course of aging at room temperature the electrical conductivity of duralumin decreases. This statement is in opposition to the assumption of Merica; further the behavior of the chemical resistance, increasing at aging, contradicts Merica's supposition. Therefore Fraenkel interprets the reason of refining by a chemical reaction in the quenched alloy, proceeding under formation of a solid solution. On the contrary the electrical conductivity increases if aging is carried out at higher temperature. This phenomenon is also confirmed on the alloy Aludur by Hall-

mann. The behavior of the chemical resistance, decreasing at this aging treatment, is in accord with the increasing of the electrical conductivity. Fraenkel supposes that by aging at room temperature a homogeneous solid solution is attained at stable state but aging at higher temperature leads to a heterogeneous system as stable state.

Hanson and Gayler and Honda and Konno recognized that magnesium plays the greater part in the refining of duralumin; added to aluminum it combines with the silicon, always present as impurity, to a chemical composition of the formula Mg_2Si.

Konno stated also that the rougher duralumin is quenched, the lower is the hardness after quenching, but the greater is the increase of hardness at aging. The opinion of Honda and Konno about the refining phenomena narrowly leans upon the proceedings at hardening of carbon steel. The improvement is brought about by the effect of the chemical composition Mg_2Si in the solid solution of $CuAl_2$ in aluminum.

The investigations of the last years proved, that alloys consisting of copper and aluminum without magnesium may be also aged; but the improvement by aging at room temperature is only inferior. These alloys must be artificially aged, that means aged at higher temperature. This fact was firstly stated by Z. Jeffries and R. S. Archer. Portevin and Le Chatelier attained the same result as Jeffries and Archer, they investigated alloys containing besides aluminum and copper also manganese.

For some time, there are also produced in Germany aluminum-copper alloys without magnesium; the alloy Lautal, consisting of 94 per cent aluminum, 4 per cent copper and 2 per cent silicon; this alloy is annealed at 490-510 degrees Cent. (914-950 degrees Fahr.) quenched and aged at 120-140 degrees Cent. (248-284 degrees Fahr.) during 16-24 hours; further there is the alloy Aeron containing 4 per cent copper, 1 per cent silicon and small quantities of manganese.

On the alloy Lautal the author investigated the influence of the aging temperature from room temperature to 200 degrees Cent. (392 degrees Fahr.) after annealing and quenching on the Brinell hardness, the yield point, the tensile strength, the elongation, etc., and comes to the conclusion that on artificial aging every aging duration at an exactly appropriate aging temperature leads to a certain degree of critical dispersion of the $CuAl_2$—particles, which produces the maximum—respectively the minimum values of the mechanical properties. This degree of critical dispersion is called by the author as critical dispersion. Exceeding of critical dispersion by too long aging at a certain temperature or also by a too high aging temperature at a certain aging duration produces coagulation of the separations to ever greater particles, combined with a decreasing of strength and an increasing of elongation and capability of shape-change.

Recently the measurement of the change of length has been employed, especially by Japanese investigators, to clear up the improvement-phenomena. The most detailed investigations on aluminum-copper-, aluminum-magnesium-, aluminum-copper-magnesium-alloys and duralumin are those, published in 1924, by Jgarasi. The results of Jgarasi's investigations cannot be explained by the

suppositions of Fraenkel or by that of Honda and Konno. They harmonize best with the interpretation of Merica, rectified in relation to the composition Mg_2Si, by Hanson and Gayler.

Refining phenomena in aluminum alloys are produced by addition of such components which are absorbed by aluminum in solid solution in a certain quantity and the solubility of those in solid state must decrease with falling temperature. The following components comply with the first condition: magnesium, copper, zinc, beryllium, lithium, silicon and the compositions Mg_2Si and $MgZn_2$. The second condition is performed by: magnesium, copper, Mg_2Si, zinc, $MgZn_2$ and finally lithium used as refining component in the alloy Skleron.

Up to the present day we have not succeeded in finding an alloy surpassing duralumin in every respect. The solution of the question of refining and the investigation of the critical point of aluminum will it make perhaps possible to find even better alloys. For the latter investigation the manufacture of an aluminum of about 99.9 per cent may be of great importance.

Abstracted by Dr. Hans Pollack, Germany.

ON THE SPECIFIC HEATS OF CARBON STEELS. By Sabro Umino. Kinzoku no Kenku. Vol. 3, No. 4, 1926, page 225-246.

The author measured the specific heat of carbon steels by means of the method of mixture. Twelve kinds of steel containing different amount of carbon ranging from 0.09 to 2.84 per cent were investigated in the range of temperatures from 23 to 1250 degrees Cent. The results of experiments are summarized below:—

1. The specific heat of carbon steels increases with the rise of temperature up to the critical range, after which it remains perfectly constant.
2. The heat of the A_1 transformation for different steels was measured. It increases linearly with the content of carbon up to 0.9 per cent of carbon, and then linearly decreases, tending to zero at the concentration of cementite. The heat of the A_1 transformation per gram of the eutectoid steel is 16.1 calories.
3. By means of the extrapolation of heat content-concentration curves at different temperatures, the mean specific heat of cementite was found to be 0.149 at 150 degrees Cent. and 0.220 at 850 degrees Cent.
4. The A_1 transformation during cooling consists of the change:—

austenite → martensite → pearlite (troostite).

The author not only determined the total heat of the A_1 transformation for different steels, but also the heat of transformation from austenite to martensite and that from martensite to pearlite were separately determined. The former was 5.8 calories and the latter 10.3 calories, per gram of the eutectoid steel.

Abstracted by Dr. Kotaro Honda.

NICKEL AND THE METAL INDUSTRIES. By P. D. Merica. In *Metal Industry*, June, 1926, page 239.

The original paper was presented by the author at the annual general meeting of the Canadian Institute of Mining and Metallurgy, in Montreal, Canada, March, 1926.

The author sets forth the development of the use of nickel in the plating shop, the brass foundry and in general industry. By means of a table he shows the estimated consumption of nickel in the U. S. from 1903 to 1925 and he also sets forth the world's annual production of nickel from 1885 to 1925.

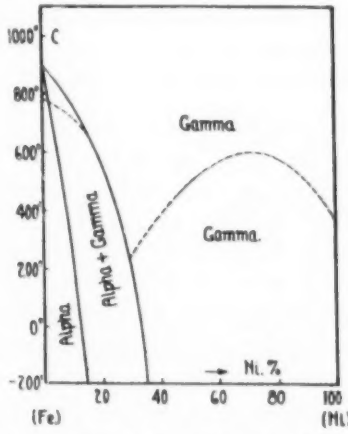
The writer describes the development work in the industry since the end of the late war and gives the present status of the market for nickel. He also states that seamless nickel tubes have been produced recently in commercial sizes. He describes the process of manufacture and says that they are used at the present time chiefly in dairy equipment.

The author is of the opinion that at present there is no cause for worry about the exhaustion of nickel mines in Canada.

ON THE RELATION BETWEEN THE LATTICE-CONSTANT AND THE DENSITY IN IRON-NICKEL ALLOYS. By Atomi Osawa; Kinzoku no Kenku. Vol. 2, No. 8, 1925, p. 809-816.

For the whole series of iron-nickel alloys, the lattice constants and the densities were determined, both for the annealed samples and those dipped in liquid air. The hardness of these samples was also measured; the results are as follows:—

1. For the whole series of iron-nickel alloys excluding the heterogeneous range (12-35 per cent nickel), the density actually observed and that calculated from the observed lattice-constants agree very closely with each other, the simple substitution of iron and nickel atoms being assumed.



2. The heterogeneous range of iron-nickel alloys lies between 12 and 33 per cent of nickel at room temperature, and between 15 and 35 per cent at the temperature of liquid air. These ranges can very conveniently be studied by means of the X-ray analysis; they can be distinguished from the homogeneous ranges by the co-existence of the spectrums of alpha and gamma types.
3. The distribution of the homogeneous and heterogeneous ranges can be expected from the equilibrium diagram (Fig. 1) of iron-nickel system proposed by Professor K. Honda. This diagram also explains the well-known heterogeneous structure of meteorites.
4. The hardness-concentration curves for iron-nickel alloys show the pres-

ence of martensite and austenite even in slowly cooled samples. The maximum hardness if attained at 21 and 27 per cent of nickel for the annealed and severely cooled samples, respectively.

Abstracted by Dr. Kotaro Honda.

HARDENING OF TOOL STEEL IN WARM WATER. By A. M. Dobrovidoff. *Journal*, Technological Institute of Tomsk (U. S. S. R.) 46, 1925, pages 31-34.

A great many test pieces of carbon steel (carbon 0.95 per cent) were prepared some of which were subjected to hardening from 760 degrees Cent. in water, warmed up to different temperatures (30-80 degrees Cent.) and some to a similar hardening with subsequent tempering at the temperatures of 160-400 degrees Cent. This investigation proposed to determine whether the process of changing the characteristics of steel is the same at reheating and at negative hardening relatively to the passing from the martensite structure to the pearlite one. Three characteristics of steel were studied: specific gravity, scleroscope hardness and resistance to fracture; the specific gravity of the test pieces before heat treating falling between the limits of 7.841-7.845 and the hardness in the limits of 40-43. The results obtained by the author being the average ones of 2 or 3 determinations are given in Table 1.

Graphical representation of the obtained results, the different process of changing of the mentioned characteristics in both ranges of experiments is noted: during reheating this changing proceeds smoothly and at the negative hardening it is accompanied by a notable leap at the temperature of water 60-70 degrees Cent.; this shows that the graduation of changing of martensite into pearlite in either case is not the same.

Abstracted by M. Oknoff and G. N. Koulginski, Leningrad, Russia.

LEAD—AS A BATH MATERIAL. By R. B. Schenck. In *Canadian Machinery and Manufacturing News*, June 10, 1926, page 14.

The author is of the opinion that careful consideration should be given to the combustion chamber. He also enumerates the items pertaining to the design and installation of a furnace to which especial attention should be given.

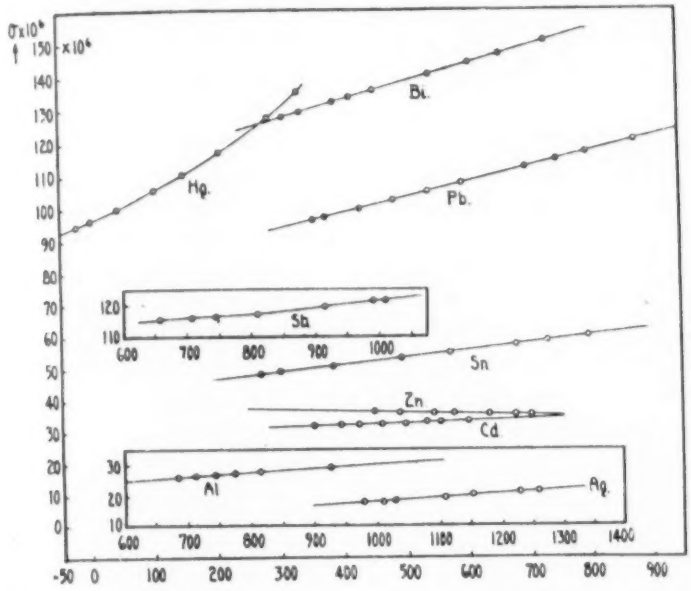
By means of a series of diagrams, he shows the various containers, the methods of mounting them, the installation of an oil-fired furnace for hardening camshafts, etc.

The author also sets forth how the flame may be effectively rotated and the method of controlling the temperature. He describes the types of coverings which may be used to avoid lead loss and dirt, and states that the size of the covering must also be taken into consideration. The kind of covering used depends upon the nature of the work. Skimming is necessary at more or less frequent intervals. The writer is of the opinion that molten salts of suitable composition are effective as a covering but expensive. They result in clean work and small lead loss, but on large pots the amount of heat radiated from the surface of the bath is great.

ON THE ELECTRIC RESISTANCE OF PURE METALS IN MOLTEN STATE. By Yosiji Matsuyama. Kinzoku no Kenku. Vol. 3, No. 4, 1926, p. 254-261.

The method of measurement is that constantly used in our laboratory (T. Ishihara; Sci. Rep. Vol. 13, 1924, 75), and the metals investigated were Hg, Sn, Sb, Cd, Pb, Sn, Bi, Al, Ag.

The curves in the accompanying figure (Fig. 2) shows the relation between the specific resistance of molten metals and the temperature; the specific



resistance of these metals increases more or less with the rise of temperature, except in the case of zinc in which a slight decrease in observable.

The following table contains the specific resistances of the molten metals at their melting points:—

Metals	Hg	Sn	Bi	Cd	Pb	Zn	Sb	Al	Ag
Sp. resist. × 10^6	93.1	48.1	126.7	32.2	95.8	37.0	115.0	25.5	17.3

Abstracted by Dr. Kotaro Honda.

MOUNTING PATTERNS REQUIRES VARIED INGENUITY—II. By H. N. Tuttle. In *Foundry*, June 15, 1926, page 479.

The author discusses the difficulty of locating the pattern parts by centerlines, drill and flask holes to measurements and obtain an absolute match. He sets forth a method for obtaining good results and is of the opinion that the pin and hole method prevents mistakes in closing.

The author by the use of various diagrams and detailed descriptions shows how the cope and drag may be accurately located so that the castings will show no shift.

DEFECTS HIDING IN STEEL CASTINGS. By F. J. Stanley. In *Iron Age*, July 1, 1926, page 12.

The author sets forth in his paper some of the difficult defects to detect and enters quite comprehensively into the causes of porosity, blowholes, cracks and many other defects and states how to prevent them. He is of the opinion that manganese and silicon, deoxidizing agents, are effective in the elimination of porosity. Shrinkage cavities are a source of annoy-

ance and are difficult to detect and the author says there is but one cause and that is insufficient liquid metal to satisfy the demands of contraction in cooling. Small defects are often caused by wrong patterns which prevent feeding properly. Cheap patterns are frequently a source of trouble. Unremitting intelligent direction would seem to be the solution of the problem of making non-defective steel castings, is the opinion of the author.

REDUCING THE COST OF CARBURIZING TRANSMISSION GEAR STOCK. By J. B. Nealey. In *Iron Trade Review*, June 3, 1926, page 1431.

Scientific principles applied to the requirements of mass production have greatly contributed to the rapid development of the automobile industry. Simplification of design, economies in production and the manufacture of tougher and more durable steels have made possible the average priced car. The author is of the opinion that carburizing, which is one of the most widely used branches of heat treatment, is of vast interest to the metallurgist, because of the difficulty in obtaining evenness of heat. He also thinks that uniformity of case is essential. He gives data on operating and other costs and also cost of carburizing per pound. By means of charts, photographs and tables the paper is made concrete.

THE DEVELOPMENT OF THE MANUFACTURE OF PUDDLED STEEL IN ENGLAND AND AMERICA. By H. Saemann, Nürnberg. *Stahl und Eisen*, March 31, 1926, p. 436-441.

The author outlines briefly the development of mechanical puddling during the last century.

The modern American puddling works utilize the old ideas of bygone days; the obtained successess are founded on the better constructive performance of the furnace, on the use of best qualified refractory materials, on the increase of the furnace output, on the construction of productive mill trains and machines for working up the puddle balls.

The author describes the puddling plant and the furnaces of the Lebanon Iron Co., further a type of puddling furnaces being well adapted for puddling of scrap, the Roe puddling machine of the Reading Iron Co. and finally the James Aston process for the manufacture of wrought iron.

The fact that the manufacture of wrought iron has anew gained in importance is not only connected with the reduction in price of the product, but also with the recognition of the valuable properties of wrought iron by the consumers. *Abstracted by Dr. Hans Pollack, Germany.*

HIGH QUALITY CAST IRON. By Dr.-Ing. Th. Klingenstein. Zeitschrift des Vereines Deutscher Ingenieure, March 20, 1926, p. 387-90.

Cast iron is classified in: (1) ordinary machine casting with tensile strengths up to 21,500 pounds per square inch, (2) high quality machine casting with tensile strengths up to 25,600 pounds per square inch, (3) cylinder casting with tensile strengths up to 37,000 pounds per square inch, (4) different special castings.

The tensile strength of high quality cast iron is from 25,600 to 37,000 pounds per square inch and even up to 57,000 pounds per square inch, corresponding to a Brinell hardness from 180 to 210 and even 240. These

numerical values have been ascertained on test bars of (30mm) 1.18 inches in thickness. The cast iron diagram, laid down by Maurer, is only applicable to normal speed of cooling; this latter and with it the structure is influenced by the amounts of carbon and silicon and by the thickness of the casting. The author gives a diagram showing the structure of cast iron in relation to the amount of carbon + silicon and on the thickness. The structure of high quality cast iron consists of a pearlitic matrix and of graphite, which affects the tensile strength in a high degree by the quantity and the manner of its separation. Therefore the different methods of manufacturing high quality cast iron are founded on the influence of the total carbon content, which should be as low as possible, and by this also on the separation of graphite. Then the author mentions briefly: the Thyssen-Emmel process, the details of which is not generally known, the process of the Maschinenfabrik Esslingen, accomplished in the Wüst furnace, an oil-fired reverbatory furnace and the melting and refining in the electric furnace. Another process for manufacturing high quality cast iron with an eutectic graphite structure was described by Schütz. The investigations of Piwowarsky hitherto existing show that the formation of graphite is essentially influenced by overheating the cast iron.

Abstracted by Dr. Hans Pollack, Germany.

ON THE RELATION BETWEEN THE LATTICE-CONSTANT AND THE DENSITY IN IRON-CARBON-NICKEL ALLOYS. By Atomi Osawa. Kinzoku no Kenku. Vol. 3, No. 4, 1926, p. 247-253.

In the same way as in his former experiment, the author investigated the above mentioned relation for iron-carbon-nickel alloys, that is, for nickel steels. The results are as follows:—

1. By means of the X-ray analysis, the measurements of the specific density and the hardness, the heterogeneous range was found to be 5-22 per cent at room temperature and 5-34.8 per cent at liquid air temperature, the carbon content being 0.5-0.8 per cent.
2. In the iron-carbon-nickel alloys, a certain amount of carbon seems to dissolve in the gamma phase. For example, at 35 per cent nickel, 0.46 per cent carbon and at 60 per cent nickel, 0.18 per cent carbon are dissolved in the gamma phase. By the dissolution of carbon, the lattice-constant of the gamma-phase increases by 0.006-0.007 angstrom units per gram of carbon.
3. In the iron-carbon-nickel alloys, the maximum hardness is considerably greater than that in the iron-nickel alloys, and takes place at much lower concentration of nickel.

Abstracted by Dr. Kotaro Honda.

ON THE HEAT OF TRANSFORMATION IN NICKEL AND COBALT. By Saburô Umino: Kinzoku no Kenku. Vol. 3, No. 5, 1926, page 228-293.

The author measured by the same method as before the specific heat of nickel and cobalt at various high temperatures, and calculated the heat of transformation in nickel and cobalt to be:—

Nickel: heat of magnetic transformation = 2.01 calories;
Cobalt: heat of magnetic transformation = 2.00 calories,
Cobalt: heat of new allotropic change at 460 degrees Cent., from the hexag-

onal to the face-centered lattice during heating (discovered by H. Masumoto) = 1.04 calories.

Abstracted by Dr. Kotaro Honda.

ON THE SOLUBILITY OF CARBON IN PURE IRON AT ROOM TEMPERATURE. By Yukio Yamada: Kinzoku no Kenku; Vol. 3, No. 5, 1926, page 294-297.

By means of the electric resistance method, the specific resistance of 12 kinds of low carbon steels containing from 0.01 to 0.089 per cent of carbon were measured. The resistance-concentration curve was linear. If the limit of solubility of carbon lies within these concentrations, the curve must have a break point; this being not the case, it is to be concluded that the solubility of carbon in pure iron at room temperature is less than 0.01 per cent. This result agrees with that of Yensen. The solubility of carbon at the A_1 point is already known to be 0.035 per cent.

Abstracted by Dr. Kotaro Honda.

HARDNESS OF SOFT METALS. By Richard Baumann. Zeitschrift des Vereines Deutscher Ingenieure, March 20, 1926, p. 403-404.

Three hardness test methods, the Shore method, the Brinell method and the ascertainment of shock-hardness have been examined.

The scleroscope type, Schuchardt und Schütte, gives proportionally little values on soft metals; therefore for measuring the hardness of such metals a second hammer is used. The ratio of the hardness numbers, ascertained with the two hammers, changes from 0.69 (rolled brass) to 0.40 (annealed aluminum), while the ratio given by the manufacturer amounts 0.563.

For testing the hardness of soft metals after the Brinell method it is advantages to apply a 10-millimeter ball and a load of 250 kilograms. The load should be applied for 30 seconds. The hardness numbers obtained by application of balls of different diameters and different loads vary greatly.

With a shock hardness tester, type Baumann Steinrück, a gaging line was determined by testing different metals. The ball used for this test had a diameter of 10 millimeters, the applied shock-intensity = 1. The shock-hardness numbers determined on the gage line characterize the hardness of the tested metals in a satisfactory manner.

Abstracted by Dr. Hans Pollack, Germany.

OXYGEN AFFECTS CHARCOAL IRON. By J. R. Eckman, Louis Jordan and W. E. Jominy. In *Foundry*, July 1, 1926, page 506.

The theory that strength increases with oxygen content is not confirmed by tests made by the Bureau of Standards.

This paper was presented by W. E. Jominy at the American Foundrymen's Association meeting in Milwaukee and compares the mechanical properties of charcoal and coke pig irons and of the remelted cast irons from these two types of pig iron. Mr. Jominy called attention to a difference in the size and form of the graphite in the strong and weak castings and described them. The Ledebur method for oxygen and results obtained by its use are set forth. Table I gives Johnson's Values for Oxygen in Strong and Weak Pig Irons.

Reviews of Recent Patents

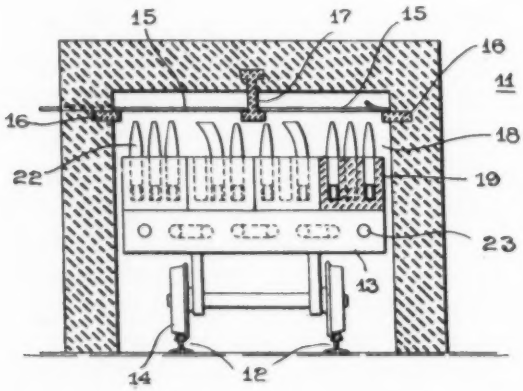
By
NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City
Member of A. S. S. T.

1,588,534, **Process for Treating Iron Castings, Harry A. Engman, Jr., of Goshen, Indiana, Assignor to Engman Range Eternal Co., of Goshen, Indiana, a corporation of Indiana.**

This patent describes a process of treating malleable iron castings which differs from the prior practice in that the castings are polished as they come from the mold and then subjected to the annealing temperature. This reversal of steps is claimed to produce a polished malleable casting having greater rust resisting properties than the same kind of casting which is polished after annealing.

1,588,641, **Electric Heat Treating Furnace, James C. Woodson, of East Pittsburgh, Pennsylvania, Assignor to Westinghouse Electric and Manufacturing Company, a corporation of Pennsylvania.**

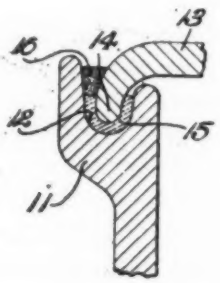
This patent describes a continuous tunnel furnace and apparatus for heating selected portions of an article to be annealed. The furnace comprises a tunnel kiln 11 heated preferably by resistance wires 15 embedded



in refractory insulating elements 16 and 17 at the top of the furnace. 13 represents a car traveling on the rails 12 through the furnace, which car may be provided with the coiled pipe 23 through which a cooling fluid is run. Supported by the car 13 are a series of insulating blocks 19 having cavities therein to receive the end of the article which is not to be annealed. As illustrated, the article, such as harrow teeth 22, may be inserted in the holes in the refractory blocks 19 so that the base of the article will be kept insulated and cool by the refractory blocks while the upper portion or point of the article will be heated as it passes through the furnace to the required temperature for annealing.

1,588,725, Sealing Material, Herbert Martin Edward Heinicke, of Elgin, Illinois, Assignor to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York.

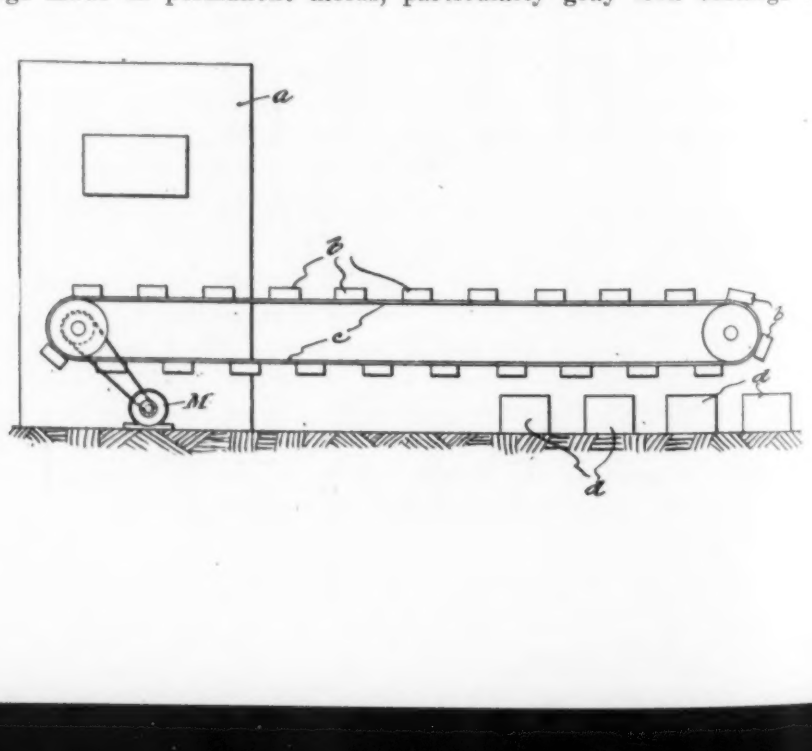
This patent describes an improvement in sealing compounds for annealing boxes, pots or the like, in which in addition to the loam or fire clay used to seal the lids on annealing containers, a fusible material is used which will fuse and run into the cracks, which appear in the loam



or fire clay as it is heated. This fusible material may be soda ash (sodium carbonate), borax or any stable salt which will fuse at a comparatively low temperature. As shown in the figure, the top 11 of the annealing pot is provided with a groove 12 into which the rim 14 of the cover 13 projects. In this groove the ordinary refractory material, such as fire clay or loam 15, is placed to heat the edges of the container and above the loam or fire clay is placed the fusible sealing mixture 16 so that during the heating, when the fire clay or loam cracks or shrinks, the sealing mixture will fuse and quickly run into the cracks or shrink cavities to maintain a seal on the pot cover.

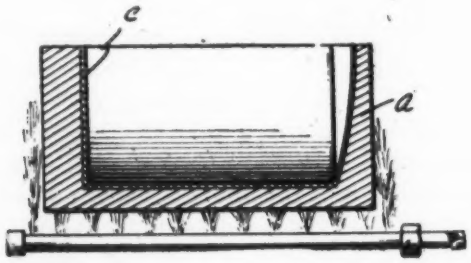
1,589,013, Method of Annealing Metal, Harry S. Lee, of Plymouth, Michigan, 1,589,014, Permanent Mold.

Patent No. 1,589,013 describes a method and means for annealing castings made in permanent molds, particularly gray iron castings which



are often chilled in the casting in a metal mold. In the drawings, **a** indicates a furnace for melting the metals and from which the metal is poured into the molds **b**, which are traveling on a continuous belt or conveyor **c** and driven from any suitable source of power **M**. At the end of the conveyor, opposite the furnace **a**, a plurality of tanks **d** are provided which are filled with powdered kieselguhr, diatomaceous earth or the like, so that when the castings of the molds **b** are dumped in the tank **d** the powdered kieselguhr acts somewhat like quick-sand to very quickly surround the casting and protect it from the loss of heat, to permit slow cooling and exclude oxygen from contact with the heated surface thereof.

Patent No. 1,589,014 describes a permanent mold for the casting of metals therein, provided with a heat-resisting lining which will increase its life and prevent chilling of the casting. The lining consists of a mixture of one part of borax to four parts of kieselguhr with water as a carrier,



which mixture is preferably sprayed slowly over the surfaces of a mold heated to 200 to 300 degrees Fahr. The mixture covers the surface of the mold with a fine chalk-like coating. When the metal is poured into the mold at 2000 degree Fahr., the borax melts and fuses the mixture in the mold providing a glassy, insulating lining **C** on the interior of the mold **A**.

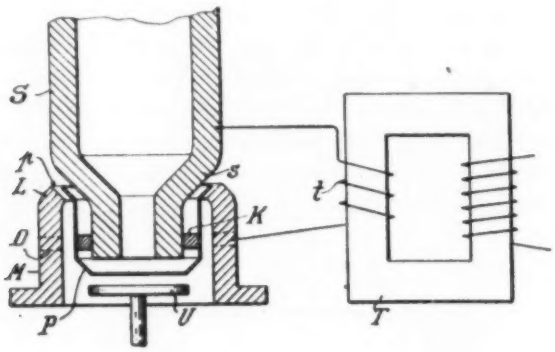
1,589,062, **Iron Casting, Joseph Ernst Fletcher, of Dudley, and Horace John Young, of Whitley Bay, Northumberland, England.**

This method describes a method of producing iron castings of great homogeneity and toughness, having a high resistance to wear, a high tensile strength and a capacity to withstand shocks. The iron employed contains preferably less than 3.5 per cent of carbon and the other elements as normally found in commercial cast iron. Castings are preferably produced in sand, plaster or graphite molds, using chills where necessary, under conditions to produce a predominantly pearlitic structure. The casting is then heated to the Ac_1 point and cooled to form an austenitic structure, reheated to a point below the Ac_1 point and cooled to decompose the austenitic structure and form an intermediate pearlitic and austenitic structure having the desired properties.

1,589,235, **Device for the Local Annealing of Pressed Parts, Edmund Schroder, of Berlin, Germany.**

This patent describes an apparatus for annealing selected parts of drawn products as, for instance, the rim and walls of a deep drawn pot,

such as P. The apparatus comprises a pedestal or matrix M having a beveled rim p adapted to receive the rim or flange of the pot or other article to be annealed, and a hollow plunger s fitting into the opening in the matrix M and into the top of the pot P and carrying a contract ring K adjustably secured to the outside of the plunger s and of such a diameter as to extend between the plunger of the pot P to make contract



therewith. By suspending the pot within the matrix M and inserting the plunger therein within the required distance, and passing a current from the transfer T through the matrix and plunger and the portion of the pot P which is between the top thereof and the contract ring K, this upper portion of the pot may be heated to a sufficient temperature to relieve the drawing strains and anneal the same. When the pot has been heated to the required temperature, the current may be turned off, the plunger s raised and the pot P removed from the matrix by means of the plunger U.

News of the Chapters

STANDING OF THE CHAPTERS

IN the July issue of TRANSACTIONS appeared the relative membership standing of the 29 chapters of the Society as of May 1, 1926, and as of June 1, 1926. The tabulation which appears below shows the relative membership standing of the chapters on June 1, 1926, and July 1, 1926.

STANDING OF THE CHAPTERS AS OF JULY 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit .....(380)	1. Lehigh Valley .(140)	1. Los Angeles ...(72)
2. Cleveland .....(374)	2. Hartford .....(135)	2. Tri City .....(65)
3. Philadelphia ...(356)	3. Golden Gate ..(129)	3. Rockford .....(62)
4. Chicago .....(319)	4. Syracuse .....(100)	4. Washington ...(62)
5. Pittsburgh .....(318)	5. Milwaukee .....(99)	5. New Haven ....(58)
6. New York .....(260)	6. Cincinnati .....(85)	6. Worcester .....(56)
7. Boston .....(238)	7. Indianapolis ...(84)	7. Rochester .....(54)
	8. St. Louis .....(76)	8. Schenectady ...(48)
	9. Buffalo .....(57)	9. Montreal .....(48)
	10. North-West ....(48)	10. Toronto .....(47)
		11. Rhode Island...(43)
		12. Fort Wayne ...(33)
		13. Springfield ....(30)

STANDING OF THE CHAPTERS AS OF JUNE 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit .....(386)	1. Hartford .....(138)	1. Los Angeles ...(74)
2. Cleveland .....(376)	2. Lehigh Valley..(137)	2. Tri City .....(66)
3. Philadelphia ...(356)	3. Golden Gate...(129)	3. Rockford .....(62)
4. Pittsburg .....(317)	4. Syracuse .....(101)	4. Washington ...(61)
5. Chicago .....(312)	5. Milwaukee ....(100)	5. Worcester .....(57)
6. New York .....(255)	6. Cincinnati .....(83)	6. New Haven.....(56)
7. Boston .....(234)	7. Indianapolis ...(82)	7. Rochester .....(55)
	8. St. Louis.....(76)	8. Schenectady ...(47)
	9. Buffalo .....(56)	9. Toronto .....(46)
	10. North-west ....(48)	10. Rhode Island ..(43)
		11. Montreal .....(35)
		12. Fort Wayne....(32)
		13. Springfield ....(30)

There were 77 new and reinstated members, 44 lost by arrears, and 15 resignations and deaths, leaving a net gain for the month of 18. The total membership of the Society at the present time is 4028.

GROUP I—The first two chapters in Group I suffered a loss, Detroit being 6 and Cleveland 2 below their readings on the previous report. This was due

to non-payment of dues, of which Cleveland and Detroit both had 7, and also on account of resignations.

GROUP II—Congratulations again to Lehigh Valley, who jumped from No. 2 to No. 1, and is again at the head of the group. Lehigh Valley was in first place for the month of April, but Hartford passed them in May, and Lehigh Valley is back on the job again with a lead of 5 over Hartford. The remaining chapters in this group are occupying the same position as last month.

GROUP III—Los Angeles continues to head this group with a lead of 7 members over Tri City. Worcester and New Haven have exchanged places, New Haven occupying 5 and Worcester 6. The most pronounced change in Group III was the addition of 13 new members to the Montreal Group, giving them a total of 48, 1 above Toronto and tied with Schenectady for 8th position.

INDIANAPOLIS CHAPTER

Owing to the great enthusiasm and interest shown by the members of the Indianapolis Chapter who live in nearby cities, the executive committee arranged for a special feature program endeavoring to show the officer's gratitude to the numerous members and guests coming to our city for the monthly meetings. The number of out-of-town members and guests have increased continually at each successive meeting showing that they do enjoy the good-fellowship incidental to the technical and educational programs.

On Monday evening, May 10, the last of our 1925-1926 meetings' dinner was served very promptly to more than 125 members and guests, many of whom came from nearby cities and towns, Anderson, Indiana, alone furnishing thirty. As a rather long program had been planned, only essential business was discussed, and immediately after the dinner, entertainment was given full sway.

Through the courtesy of our members who are affiliated with The Remy Electric Division of General Motors Corporation at Anderson, Indiana, eight of their foremost entertainers journeyed here and afforded so much fun that it was very difficult for our chairman, W. G. Praed, to call for a cessation of the fun and proceed with the addresses. Max Terhune, a Remy favorite, demonstrated that he knew ventriloquism as well as manufacturing, and many good jokes brought forth so much laughter that one could scarcely conclude that the audience were sober minded steel workers. Then came Messrs. Crim and Counceler with their harmonicas setting a high mark for the subsequent acts. Messrs. Stome, Haynes, Thompson and Ice then showed that they not only knew the best songs but could sing them so that all the cares of the shop and heat treatment could be forgotten. Max Terhune then gave a series of "Barn-yard" imitations. His whistling was so good that the audience could just imagine itself down in the barn-yard watching the farmer trying to referee a free for all between the dogs, hogs and other contenders. Dick Miller, president of The City Trust Company, Indianapolis, a shining light in Indianapolis' financial circles and a great "Booster" for Indianapolis, took the audience back twenty-five years when all industry was individually owned and gradually traced the development of industry down to the present day of stock ownership in which the men working in the different plants are stock-

holders and bond-holders not only of the company for whom them are working but also of other companies. The great change in ownership and responsibility is directly responsible for the remarkable development and success of the giant industries such as the American Telephone and Telegraph Company, The United States Steel Corporation, The General Motors Corporations and thousands of other, including railroads, mining, chain stores, etc. He repeated that never before in the history of the world had the individual the same opportunities as exist here in the United States today. Knowledge, confidence and persistence means success to all.

Thomas H. Wickenden, metallurgist from the development and research department of The International Nickel Company of New York City, gave an interesting and inspiring illustrated lecture on "Automobile Design and Automotive Steels," and gave the audience a good idea of the necessity of combining scientific knowledge with actual "road testing" in the development of an automobile which will stand the hard usage given it by the average driver. He stressed the importance of making the proper selection of steels for the particular purpose and then giving these steel parts the proper heat treatment so as to be able to make use of all the strength possible. Failures being expensive in dollars and cents as well as jeopardizing human life, it is always best to use the best materials and give the materials the best known treatments. Discussion followed.

The officers holding office in the local chapter during the past year were re-elected for the coming year. These include, W. G. Praed, assistant superintendent of The Link Belt Company, as chairman; Carleton B. Edwards, Republic Creosoting Co., vice-chairman, and Clarence H. Beach, steel sales agent representing Bliss and Laughlin, Inc., as secy-treas.

Executive Committee includes:

Max Thoms, Marmon Motor Car Co., Indianapolis.

O. L. King, E. F. Houghton Co., Indianapolis.

John Beyers, superintendent, Indpls. Drop forging Co., Indianapolis.

Wallace, chief engineer, J. D. Adams & Co., Indianapolis.

Roger Emmert, tool supervisor, Remy Electric Co., Anderson, Indiana.

David Killion, Link Belt Co., Indianapolis.

The next meeting will be held early in September just prior to the annual convention at Chicago. *C. H. Beach.*

LOS ANGELES CHAPTER

The regular monthly meeting of the Los Angeles Chapter of the American Society for Steel Treating was held June 12, 1926.

At two o'clock in the afternoon of Saturday, June 12, about eighty members and guests of the Society gathered at the Union Tool Company's plant in Torrance and were conducted by Wm. S. Grau, the superintendent of production, through the plant. This concern specializes in the manufacture of oil well drilling equipment and kindred products. The plant covers about forty-three acres of ground and is equipped to make all kinds of machinery for the oil well drilling industry from pig iron to the finished product.

The steel foundry was first visited, and while the visitors were being conducted through that department an ingot heat was poured from one of the

electric furnaces. Much interest was taken and many questions asked. Next the iron foundry was inspected and then all went to the machine shop. This building is some thousand feet long by one hundred feet wide and seemed to interest with its hundreds of machine tools and variety of jobs in process, each individual in some respect or other.

The trip through the forge shop opened the eyes of all as this is one of the largest on the coast and has two forging presses as well as about a dozen steam hammers and several forging machines.

The heat treating department came next, and needless to say a thorough investigation was made.

After that the tool room was looked over and some of the master gages were taken from the vault to give those desiring information along that line a chance to ask about them.

One of the noticeable things about the party was the interest taken by members in the general design and machining methods over and above that which one would expect from steel treaters. Besides this, several members inquired into routing, order and cost methods and such queries were answered.

At the conclusion of the inspection tour, Chairman Stiles of the local chapter, in behalf of the members thanked Mr. Grau and J. O. Bishop, who assisted Mr. Grau, for the privilege of inspecting this up-to-date plant.

Mr. Stiles called to the attention of members and guests present the plans the Los Angeles Chapter had made to start a course in practical metallurgy and heat treatment of steel.

The first lecture of a course of twelve was given Tuesday night, June 29, by Prof. W. Howard Clapp of California Tech, Pasadena. Thirty-eight members have enrolled, and from all indications we feel the course will be a great success and one from which the members will derive a great deal of benefit.

E. C. Black.

PITTSBURGH CHAPTER

The June meeting of the Pittsburgh Chapter was postponed from the usual first Thursday of the month to Friday, June 18, in order that the chapter might avail itself of an invitation to visit the Heppenstall Forge and Knife Company works.

Somewhat over one hundred members assembled at the executive building at four o'clock and were escorted through the works in groups.

The melting department was first visited at which time a heat was tapped and poured.

Considerable time was spent in the forge department, as the members were greatly interested in the extreme care and precision used in the forging of die blocks.

The shear blade department was next visited and finally the heat treating and general machine shop departments.

On the way back to the executive building, the chemical, metallographic and testing laboratories were shown.

At 6:30, the members assembled in the company dining room where an elegant dinner was served during which there was music and speeches.

At the conclusion of the dinner, the tables were removed, and instead

of the usual paper, a good vaudeville show was put on which was very much enjoyed. There will be no chapter meetings during July and August.

Harry A. Neeb, Jr.

ST. LOUIS CHAPTER

America is ahead of European countries in the treatment of steel because of its mass production, notwithstanding the great progress all countries made during the war when the need for war tanks created a demand for better and lighter steel. This was brought out at the June meeting of the St. Louis Chapter by George S. Rogers, research department of E. F. Houghton and Company, Philadelphia. Mr. Rogers recently returned from abroad where he has made a comparative study of heat treatment in Germany, France and Italy.

While Mr. Rogers did not approve the governmental ideas of the Italian Dictator Mussolini, he stated that under the new regime Italian steel men have shown more progress than other countries in the east. Italy has followed the American idea of mass production, he said.

That better results have come from the use of liquid salt baths in forging, hardening and tempering tool equipment was a point made in the address. It was shown that the 400,000 machinists employed by the railroads are learning the value of tools treated by this process.

The talk was directly in the line of interest of the members present. Other features touched upon were in reference to how the oil industries and the mining interests are following the trend of better heat treatment. The subjects was "Progress with Metal Industries."

The meeting was held in the American Hotel Annex, and was well attended. A vote of thanks was extended the speaker, which being interpreted in the language of the country editor would mean: "Come back again, George!"

C. G. Werscheid.

(Continued from Page 310)

tend to show an even harder composition than martensite, especially in the hyper-eutectoid steels. This position also seems to be a transition point in the solid solution of Fe_3C, wherein it changes to some other carbide, possibly as Austen states, to $Fe_{24}C$, and thence transforming into still another carbide, present in martensite—possibly the crystalline carbide. As this transformation seemed to be accompanied by a slight swelling or expanding of the metal, and a later reduction when the change to martensite, or to the crystalline carbide, Fe_3C, is fully accomplished, it was thought that possibly the hypothesis was correct, though now that thought is no longer held or expressed.

From the above, the contention is that instead of trying to form separate hypothesis for each and every step of the transition from gamma to beta to alpha irons, these formations should be considered simply as a part of the transformation range and that the transformation was arrested at these points, showing these stages of the transition, which, in this case, has been considered as separate formations, and yet seemingly held in the one phase of alpha iron, purely an analogy hardly to be accepted—notwithstanding the position that Dr. Hanemann occupies in the field of metallurgy.

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Items of Interest

THIRTEEN graduates of colleges and universities have been appointed Research Fellows to conduct an unusually extensive program of studies in mining and metallurgy at the Carnegie Institute of Technology during the coming year, according to an announcement. The work, as in the past, will be carried on by the Department of Mining and Metallurgical Engineering, in cooperation with the Pittsburgh Station of the U. S. Bureau of Mines and under the direction of two advisory boards of engineers and business men representing the mining and metallurgical industries.

The appointees and the institutions from which they were graduated are Clarence L. Corban and G. R. Fitterer, Rose Polytechnic Institute; Briant F. Branting, University of Utah; R. L. Geruso, Rensselaer Polytechnic Institute; Charles H. Gilmour, Syracuse University; E. R. Perry, Hastings College; Miles B. Royer, Pennsylvania State College; E. J. Talbert, University of New Hampshire; N. A. Tolch, University of Illinois; Carl E. Traubert, University of Denver; Stanley P. Watkins, Birmingham Southern College; R. E. Wiley, University of Minnesota; Donald C. Jones, Carnegie Institute of Technology.

Of the thirteen investigators, five will study problems in metallurgy and eight have been assigned to carry on research in problems relating to coal mine engineering. The program of metallurgical studies will be supervised officially by an advisory board of Pittsburgh District Steel men and engineers. The coal mining investigations will be made under similar conditions with an advisory board of coal operators and mining engineers.

Four of the studies, it is announced, will be financed by the Carnegie Institute of Technology, while the remainder of the work will be underwritten by the industries. Among the contributors are the American Gas Association which is interested directly in a study of "warning agents for manufactured gas," the National Coal Association, the New York Edison Company, and other industrial enterprises.

Senior investigators to assist the Research Fellows will be furnished by the Bureau of Mines. Problems have been selected and assigned for the year as follows: "Constitution of Low Temperature Tar," by B. F. Branting, Fellow, and R. L. Brown, Senior; "Coal Ash Fusibility as related to Clinkering," by C. L. Corban and E. J. Talbert, Fellows, and P. Nichols and A. Selvig, Seniors; "Formation and Identification of Inclusions in Steel," by G. R. Fitterer, Fellow, and C. H. Herty, Senior; "Solubility of Iron Oxide in Iron and Its Effect on Physical Properties of Pure Iron," by R. L. Geruso, Fellow, and C. H. Herty, Senior; "Flammation of Fine Sizes of Coal Dust," by C. H. Gilmour, Fellow, and C. M. Bouton, Senior; "Electric Power of Storage Batteries vs. Trolley Locomotives," by Donald C. Jones, Fellow, and L. C. Illsley and C. W. Owings, Seniors; "Warning Agents for Manufactured

(Continued on Page 34 Adv. Sec.)

Employment Service Bureau

This bureau is for all members of the Society. Want ads will be printed at the following rates: minimum of 30 words $0.50; each additional word $0.02.

This service is also for employers, whether members of the Society or not. Rates for this service are as follows: minimum of 50 words $1.00; each additional word $0.02. Fee must accompany copy.

Address answers care of AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, unless otherwise stated.

POSITIONS WANTED

WANT POSITION AS METALLURGIST. Can take charge of physical, chemical and microscopic laboratory work; supervise all types of heat treating; extensive experience in case hardening. Have done some sales and service work. College graduate, 36, married. Have held responsible positions. No restrictions as to location, although central-west preferred. Address 7-5.

LABORATORY ASSISTANT, age 19, desires connection with some physical laboratory. Has had one year and a half experience in all metals and their alloys. Experience on short notice. Philadelphia or Pittsburgh district preferred. Address 8-15.

POSITIONS OPEN

SALESMAN. Graduate of mechanical or electrical engineering course, preferably from class of '23 to '26, for service and sales work on Hump and Homo Heat Treating Furnaces. Short training period necessary before active field work. Apply by letter only, giving age, marital state, education, schools attended, experience, etc. State salary expected and enclose photograph. Address—Personnel Dept., Leeds and Northrup Company, 4901 Stenton Ave., Phila., Pa.

SALESMAN WANTED—Young man thoroughly competent to sell high grade tool steel—preferably one acquainted with Philadelphia territory—must furnish first class references. Good opportunity for right man. Address 8-10.

POSITIONS OPEN

WANTED: Furnace expert for selling, installing and operating new type of automatic temperature control equipment for gas-fired and oil-fired furnaces and electrical ovens and furnaces, also steam heated processes. Must have real practical knowledge of furnaces and experience with automatic control. Engineer or metallurgist preferred who desires extensive traveling, visiting great numbers of industrial plants. In answering advise experience. Fine opportunity for right man. Address 8-5.

DIE CUTTERS on replace work at Wallingford, Connecticut. Address 8-25.

WANTED

UNIVERSITY GRADUATE with at least eighteen months experience in the metallography and photomicrography of carbon and some alloy steels. Location near Pittsburgh. Address 8-20.

The Clearing House

For the Sale of Used Equipment

		1 time	2 times	3 times	4 times
Rates per Insertion	1 inch[1]	$ 4.50	$ 4.25	$ 4.20	$ 4.00
	2 inch	8.50	8.00	7.75	7.50
	3 inch	12.00	11.50	11.25	11.00

[1]There are 12 lines to an inch. A charge of 40 cents per line will be made for extra lines.

FOR SALE

FOR SALE—1 Bellis Triple Pot Furnace for High Speed Steel, pots 10" dia. x 16" deep. Excellent condition, has never been used. Address 7-15.

WANTED—A used Brinell machine in good condition. Address 8-35.

Gas,'' by E. R. Perry and E. J. Talbert, Fellows, and S. H. Katz, Senior; ''Viscosity of Open Hearth Slag,'' by M. B. Royer, Fellow, and C. H. Herty, Senior; ''Mine Timber Treatment,'' by N. A. Tolch, Fellow, and L. D. Tracy, Senior; ''Distribution of Ferrous Oxide between Slag and Metal,'' by S. P. Watkins, Fellow, and C. H. Herty, Senior; ''Case Carburizing of Steel,'' by R. E. Wiley, Fellow, and C. E. Sims, Senior.

Sir Hugh Bell was awarded this year's Bessemer gold medal at the postponed meeting of the Iron and Steel Institute held in London, June 3-4. The presentation was made by Sir Rylands, the incoming president. This is in recognition of outstanding services in the advancement of the art of the manufacture of iron and steel.

A. O. Fulton, president Wheelock, Lovejoy and Company, Cambridge, Mass., steel jobbers, has been made a member of the board of directors of the Central Trust Company, Cambridge.

It is said that the most valuable trainload of ore ever carried by any railroad was recently delivered at Niagara Falls for use by the Crucible Steel Company of America. This completed its journey of 10,000 miles from the interior of China. Its worth is estimated as slightly over a half-million dollars for about 50,000 units. Tungsten is the heaviest of all ores, being about two and one-half times as heavy as iron. Its melting point is far higher than any other known metal, about 5900 degrees Fahr. Its tensile strength after working is so great that it can be drawn out in a filament so fine that one pound will be nearly a mile and a half long. This is sufficient to manufacture 25,000 electric bulbs of the 25 watt size. Tungsten is also used in the making of high speed cutting tools and for guns, saws, punches and dies.

Tungsten was discovered in China about ten years ago. Recent troubles in China have had a deleterious effect on the mining and shipping of this material.

The International Foundry Trades Exhibition at the Royal Agricultural Hall in London held recently was a success despite the coal strike. The coal stoppage prevented a number of concerns from participating in the show, but the sixty exhibits which were on display represented the industry very fully. One of the important features was the showing of melting plants. Cupolas, sand handling machinery, molding machines, sand blast plants and sand preparing machines were also of interest. The meeting was formally opened by Sir Robert Hadfield.

W. P. Woodside, founder member of the A. S. S. T., and formerly metallurgist with the Studebaker Corporation, is now identified with the Climax Molybdenum Company of New York, in a consulting capacity. His headquarters are in Detroit.

J. E. Frederick, member of A. S. S. T., and president of the Kokomo

(Continued on Page 36 Adv. Sec.)

Metallographic Polisher

(Another Fisher Product)

Can also be used for fine grinding

12-265

12-265 Metallographic Polisher, Fisher, Motor Driven

For preparing metal surfaces. Separate heads can be used and interchanged, and are directly connected to the motor shaft. The polishing head is equipped with a counterbalanced clamping ring for holding the felt disc in position. The apparatus is completely enclosed; a bowl surrounds the head and catches the polishing liquid, which can be drawn off at the drain. The splash-shield is removable to provide for cleaning. For operation on 110 volt A. C. or D. C. Supplied as illustrated, with polishing head and felt disc.

Price $95.00

12-270 Metallographic Polisher, Fisher, Pulley Driven

Similar to No. 12-265 except base is not enclosed, and is provided with pulleys for power drive.

Price $70.00

The New Fisher Catalogue has a complete metallurgical section

FISHER SCIENTIFIC COMPANY

LABORATORY SUPPLIES

PITTSBURGH, PA. U.S.A.

(Formerly Scientific Materials Company)

Wire and Steel Company, was recently reelected president of the Indiana Chamber of Commerce.

Dr. W. P. Davey, a frequent contributor to the *Transactions* of the A. S. S. T., has been appointed professor of industrial research at Pennsylvania State College, effective September 1. Dr. Davey graduated from Western Reserve University in 1906 and received his doctor's degree from Cornell in 1914. That year he joined the General Electric Company research staff of which he has been a member ever since that time.

W. M. Corse, metallurgist and member A. S. S. T., has recently been appointed representative of the Institute of Metals of Great Britain, of which organization he is honorary corresponding secretary for the United States, to the International Foundrymen's Congress, which meets at Detroit, September 27 to 30.

Mr. Corse sailed for England July 14, to close negotiations for the American rights for the Durville patent for pouring monel metal, aluminum bronze and other similar alloys. While abroad, he will attend to a number of scientific matters pertaining to various metallurgical subjects and will visit the National Physical Laboratory, Teddington, England, and other scientific institutions in Great Britain. He will also attend the Institute of Metals meeting at Liege, Belgium, September 1 to 4.

C. J. Murray has recently resigned from the staff of The Linde Air Products Company, to become associated with the Oklahoma Contracting Company. He is now organizing a new division of that concern to engage exclusively in oxwelded pipe line construction. During his association with the Linde Company, Mr. Murray specialized in this class of work and has studied the construction problems connected with a large number of notable trunk line projects.

The Stanley P. Rockwell Company of Hartford, Connecticut, in Bulletin No. 2607 sets forth the practical results obtained by users of the Volerit method and how the Rockwell Dilatometer remedies tool-hardening troubles and reduces crackage.

The American Metallurgical Corporation has recently reported that its sales of electric furnaces for the three months ending March 31, 1926, totaled double the best previous three months' business in the company's history. Furnaces totalling 974 kilowatts were sold, with the demand ranging from 20 to 85 kilowatt units. These were sold principally in the east and middle west. The following is a list of the recent installations made by the American Metallurgical Corporation and contained in their report:

Two of the 60 kilowatt and one of 40 kilowatt for the Union Hardware Company, Torrington, Conn.; two 85 kilowatt furnaces for air superheating for the F. N. Burt Company, Buffalo; one 34 kilowatt air superheater for Better Packages, Inc., Shelton, Conn.; four 30 kilowatt pot types for the Cleveland Twist Drill Company; one 30 kilowatt pot type for the Ferry Cap & Set Screw Company, Cleveland; one 30 kilowatt pot type for aluminum Kant Score Piston Company, Cincinnati; one 40 kilowatt furnace for the

(Continued on Page 38 Adv. Sec.)

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QUALITY UNIFORMITY

FOR THOSE WHO DEMAND THE BEST
IN THEIR FINISHED PRODUCT

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MAGNET STEEL
SPECIAL ANALYSIS STEEL

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BARS

WE WILL EXHIBIT
NATIONAL STEEL & MACHINE TOOL EXPOSITION
CHICAGO
MUNICIPAL PIER SEPT. 20-24
BOOTH NOS.
212 & 216

SIMONDS STEEL MILLS
LOCKPORT, NEW YORK

Thomas & Skinner Steel Products Company, Indianapolis; one 30 kilowatt, one 40 kilowatt and two 20 kilowatt furnaces for the Chrysler Corporation, Newcastle, Ind.; two 20 kilowatt furnaces for the Pratt & Whitney Company, Hartford, making twelve units in this plant; one 30 kilowatt and one 75 kilowatt outfit for the Gray Telephone Pay Station Company, Hartford; one 75 kilowatt furnace for the Cushman Church Company, Hartford, one 30 kilowatt furnace for the American Hardware Company, New Britain, Conn., and one 30 kilowatt installation for the Torrington (Conn.) Manufacturing Company.

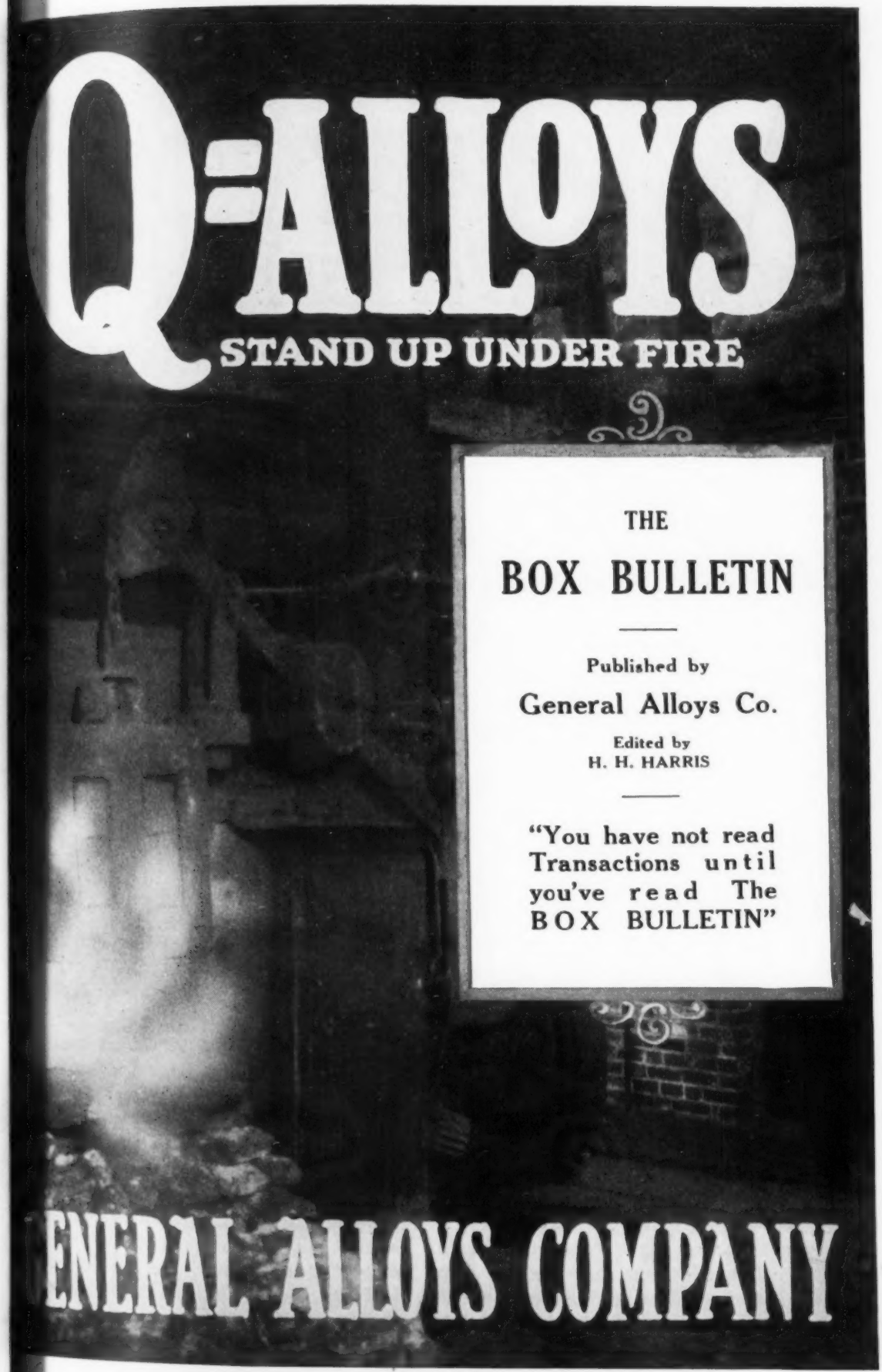
The experimental blast furnace maintained by the Bureau of Mines, Department of Commerce, at its North Central Experiment Station at Minneapolis, has been developed to the point where it is now possible to undertake the solution of special problems. One of these problems is the efficient utilization of the manganiferous iron ores on the Cuyuna range and in other parts of the country. These ores are very important because of the limited supply of domestic manganese reserves. While it is the practice at a number of plants to add small amounts of manganiferous ores to blast furnace mixtures, there is some question as to the practicability of smelting a charge containing 100 per cent of these ores.

It is desirable to know whether it is commercially feasible to use these ores, and, if so, what grade of metal can be made from them and what type of slags will give the highest recovery of manganese. More alumina occur in these ores than in straight Lake iron ores. This fact raises a question regarding the smelting of these ores. There has been considerable speculation regarding the effect of the rather large amounts of combined water present in Cuyuna Range ores.

During a recent test, about 136 tons of metal were made by the Bureau of Mines in the course of 34 days' operation of the experimental blast furnace. This test was designed to cover the important phase of the problem outlined above. The results obtained will be studied to determine whether they are complete enough to permit of drawing conclusions as regards recommending a commercially feasible process for the utilization of these ores. If this is not possible, further experiments will be made.

A study of requirements for electric-furnace refractories is being made by the Bureau of Mines, Department of Commerce. The work on this problem will follow in a general way the line of attack used in the Bureau's study of the open-hearth refractories problem. It will include a survey of general conditions and the gathering of data on refractories used, service life, probable cause of failure, etc. Chemical and mineralogical composition of used brick will be determined and an attempt made to correlate the data with that already obtained in the open-hearth investigation.

The object of an investigation being conducted by the Bureau of Mines, Department of Commerce, is to determine the cause of and means of controlling the varying carburizing and hardening characteristics of steels. The work will be carried on in cooperation with the Bureau of Standards. This is a new problem for the Bureau of Mines, although the Bureau of Standards has been working on it from the testing end. It was undertaken at the request of the steel industry and will be attacked from the standpoint of production.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STAND UP UNDER FIRE
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BOX BULLETIN
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General Alloys Co.
Edited by
H. H. HARRIS
"You have not read Transactions until you've read The BOX BULLETIN"
ENERAL ALLOYS COMPANY

THE BOX BULLETIN

NEW DEPARTMENT

Complete Information about Chicago

Established upon numerous requests from Steel Treaters planning to attend the Convention and National Steel and Machine Tool Exposition of the A. S. S. T., Chicago the week of September 20th.

I don't know why it is that all of these gazabos think I am so well versed on Chicago and its environments that I can answer any question they sling at me. However, I consider all the steel treaters friends and I want to do them a favor when I can consequently I feel inclined to answer a few of the questions and set them straight.

I do not assume any responsibility whatever for the truth or correctness of these answers, but have given my best endeavor.

You will also observe that in no instance have I mentioned that Q-Alloy is a better alloy than any other on the market. Even though I do draw the salary and dividends as President of the Company, I do not feel it advisable in departments like this to either advertise General Alloys or the superior merits of the product they manufacture.

H. H. Harris

Question: How long will the steel treaters' show last?

Answer: Boy, it will last longer than you do. It starts on Monday, runs through up to and including Friday,—you can rest up on Saturday travel home on Sunday and hang your hat on the old familiar peg on Monday morning. H. H. H.

Question: I have been using some of your Q-Alloy boxes and have had very good success with them, however, I feel it advisable to go to the steel treaters' show in Chicago and see what others have to offer in the line of boxes. Would it be possible for me to secure a certificate giving me fare and a half on the railroads?

Answer: Come right along young man. That's just why the steel and machine show is there, so that you can look over all of the products and pick the one best suited for your needs. As for a railroad certificate, if you are a member of the A. S. S. T. you can get one, if you are not you are out of luck. I might add that you are the only user of Q-Alloys that I know of who is not a member of the Society. H. H. H.

Question: What would you suggest, that I bring it along or try and get some home brew in Chicago?

Answer: My advice is to leave both of them alone. Bob Guthrie was in a hurry to get rid of some of his home brew and he poured it in the gold-fish globe. On his return he discovered that the fish had eaten their way through the globe, had killed the cat, overturned the kitchen stove and were putting the finishing touches to the family bull-dog. H. H. H.

Question: I have heard a lot about Chi- as a summer resort and also about their derful park and parking system. Could tell me whether or not the moonlight he same in Chicago as it is on the ash?

wer: You must think I'm a wise old Chicago's all right; however, let me

give you a little advice. If you want to spoon there in the dark, don't do it, just get in the light where everybody can see you. ———— H. H. H.

Question: I have been informed that the barbers in Chicago put hair restorer in their shaving cream, and I am wondering

The Gem Raiser.

whether you would recommend that I bring my own razor, and what make would you suggest?

Answer: Ever since I was knee-high to a grasshopper I have been shaving myself, nevertheless the best razor I know of is shown in the accompanying illustration. H. H. H.

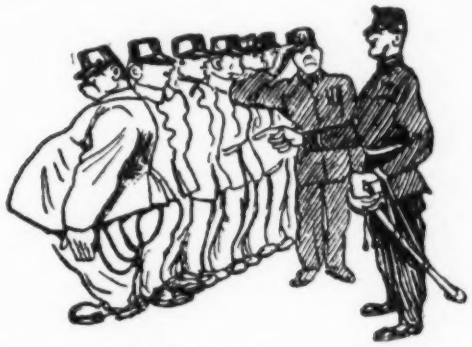
————

Question: I heard that you lived in Chicago at one time and that you were an angel to several shows that made their appearance in Chicago, and I am wondering how you expect to put on your night shirt over your wings.

Answer: I am not worrying how I'm going to get my nightshirt over my wings, what's worrying me is how I'm going to get my hat on over my horns. H. H. H.

————

Question: I understand that at the A. S. S. T. Convention they are going to get the old service men together for a little drill. Inasmuch as you were in the service, and as you are kind of portly, I am wondering how you are going to stand on the line without sticking out too far in front.

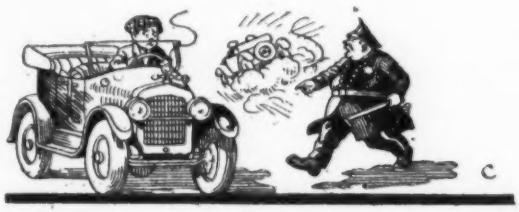


Answer: Here's the answer. H. H. H.

————

Question: Do the Chicago police have much consideration for a hick driver?

Answer: It all depends upon the type of car you have. If you are arrested would suggest that you refuse to pay the fine, stating you believe that anyone who vio-



lates the law should be imprisoned, and after they send you to jail for ten days you should offer to pay them for your board. I do. ———— H. H. H.

Question: I am taking a course in "getting fit by music"—do you think there would be an opportunity in Chicago for me to continue my exercises, or do you feel that

going up and down the pier will be sufficient exercise?

Answer: Let me suggest that if you are taking this course that you refrain from go-

ing to the grand ball on Tuesday evening, because you are liable to hear a familiar tune at the dance and start in with your exercises. H. H. H.

Question: I am a single man and plan to attend the steel show in Chicago. In case I get lonesome what would be your suggestion as to the best method of approach in order to have company.

Answer: The formula used in Chicago [illegible] to step up to the young lady and say "Y[illegible] Sir, you're my baby" and if you get awa[illegible] with it you are all set. If you don[illegible] Charity Hospital is located at 49th an[illegible] Calumet. H. H. H.

Question: I planned to get married shor[illegible] ly before the exposition and am wonderin[illegible] if you would not be so kind as to let m[illegible] have your advice as to whether you thin[illegible] the Missus would enjoy herself at the Co[illegible] vention.

Answer: So you're thinking of getting ma[illegible] ried! Hmmm, listen to me—love an[illegible] sausages are full of mystery, while seve[illegible] days without food makes one weak. Curv[illegible] of the ladies kill more men than those o[illegible] the railroads—but go ahead, courting in [illegible] canoe—honeymooning at the beach—it a[illegible] spells dishwater just the same. If you ca[illegible] swim—jump! H. H. H.

Question: Will you please publish a photo[illegible] graph of the Q-Alloy staff you expect t[illegible] have at your booth at the steel show i[illegible] Chicago?

Answer: Gladly—here goes.

H. H. H.

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